WEHST: Wearable Engine for Human-Mediated Telepresence

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ABSTRACT

WEHST: Wearable Engine for Human-Mediated Telepresence

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This dissertation reports on the industrial design of a wearable computational device created to enable better emergency medical intervention for situations where electronic remote assistance is necessary. The design created for this doctoral project, which assists practices by paramedics with mandates for search-and-rescue (SAR) in hazardous environments, contributes to the field of human-mediated teleparamedicine (HMTPM). Ethnographic and industrial design aspects of this research considered the intricate relationships at play in search-and-rescue operations, which lead to the design of the system created for this project known as WEHST: Wearable Engine for Human-Mediated Telepresence. Three case studies of different teams were carried out, each focusing on making improvements to the practices of teams of paramedics and search-and-rescue technicians who use combinations of ambulance, airplane, and helicopter transport in specific chemical, biological, radioactive, nuclear and explosive (CBRNE) scenarios. The three paramedicine groups included are the Canadian Air Force 442 Rescue Squadron, Nelson Search and Rescue, and the British Columbia Ambulance Service Infant Transport Team. Data was gathered over a seven-year period through a variety of methods including observation, interviews, examination of documents, and industrial design. The data collected included physiological, social, technical, and ecological information about the rescuers. Actor-network theory guided the research design, data analysis, and design synthesis. All of this leads to the creation of the WEHST system. As identified, the WEHST design created in this dissertation project addresses the difficulty case-study participants found in using their radios in hazardous settings. As the research identified, a means of controlling these radios without depending on hands, voice, or speech would greatly improve communication, as would wearing sensors and other computing resources better linking operators, radios, and environments. WEHST responds to this need. WEHST is an instance of industrial design for a wearable "engine" for human-situated telepresence that includes eight interoperable families of wearable electronic modules and accompanying textiles. These make up a platform technology for modular, scalable and adaptable toolsets for field practice, pedagogy, or research. This document details the considerations that went into the creation of the WEHST design.

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Kootenay Heli Rescue Society

Nelson Search and Rescue

British Columbia Ambulance Service (BCAS)

BCAS Infant Transport Team (ITT)

Justice Institute of British Columbia (JIBC)

Joint Rescue Coordination Centre Victoria (JRCC)

442 Transport and Rescue Squadron

Table of Contents

0.1: List of Figures

0.2: List of Tables

0.3: List of Abbreviations

ANT – actor-network theory

BCAS – British Columbia Ambulance Service

CAD – computer-aided design

CBRNE – chemical, biological, radiological, nuclear, explosive

EEG – electroencephalography

EOG – electrooculography

EMG – electromyography

GSAR – ground search and rescue

HBC – human-based computation

HEG – hemoencephalography

HETS – helicopter external transportation system

HMTPM – human-mediated teleparamedicine

ID – industrial design

ITT – Infant Transfer Team

JIBC – Justice Institute of British Columbia

JRCC – Joint Rescue Coordination Centre

MAS – multi-agent system

PPE – personal protective equipment

SAR – search and rescue

SAR Tech – search and rescue technician of the Canadian Air Force

SysML – systems modeling language

TPM – teleparamedicine

WEHST – wearable engine for human situated telepresence

Glossary

Computational textile: fabric or other supple wearable material that holds sensors, computing resources and communication devices. Such textiles can offer on-the-fly solutions to problems in implementing mobile telepresence networks and developing flexible, adaptive, distributed, decentralized, scalable and wearable body/environment interfaces and computing architectures.

Telehealth: Healthcare related services delivered or received, synchronously or asynchronously, over large or small spatial, temporal, social, and cultural barriers. Telehealth is enabled by interactive telecommunication, diagnostic, monitoring, and therapeutic technologies.

Industrial design: 1) "Industrial design is the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer."[1] 2) "The ultimate purpose or function of design in society is to conceive products which express and, necessarily, reconcile human values concerning what is good, useful, just, and pleasurable. However, these terms no longer possess fixed and generally accepted meanings."[2]

Equipoise: A stable state characterized by the cancellation of all forces by equal opposing forces. This equilibrium may interleave emotional, moral, intellectual, social, ethical, legal, and political interests.

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[1] www.IDSA.org. Accessed January 2008.
[2] Richard Buchanan, Branzi's Dilemma: Design in Contemporary Culture. Design Issues, Volume 14, Number 1, 1998 P11

Chapter One: Introducing the Industrial design challenge

> Without regard for my personal comfort or self-advancement, to the best of my ability and to the limitations of my physical and psychological endurance, I solemnly pledge to make every effort to return to safety, those victims of disaster entrusted to my care by the assignment of the mission to which I have consented. These things I shall do: 'That others may live.'[3]

Twenty-first century research about, through, and for [4] industrial design involves creating new knowledge of – and for – the experiences of designers, design clients, and design environments and situations that are a part and parcel of the complexities of the world. Industrial design responses must be attuned to how particular problems produce paradoxes and on-going challenges that require reflection. Our designs may exacerbate and/or ameliorate heterogeneous global problems of overpopulation, economic instability and disparity, famine, infectious disease, war and genocide, pervasive and persistent pollutants, nuclear proliferation, disruptive technologies, mass extinction, and climate change. Industrial design is only one among many disciplines recognizing and responding to these significant and widespread global challenges.

However, while all research programs and research material is designed, design is an oft-times overlooked aspect of knowledge creation. I am an industrial designer. Industrial design, design that becomes a part of the way we bring about our societies, obliges industrial designers to be as cognizant as possible of the potential impact of our design decisions and choices, to understand their interconnection to other processes and systems.

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[3] SAR Tech Maxim - Transcribed from the Canadian Forces School of Search and Rescue (CFSSAR), RCAF19 Wing Comox Airbase, Vancouver Island, B.C., 2009.

[4] This tripartite categorization of design research is widely discussed and debated in design literature, and is attributed to Sir Christopher Frayling who further attributes their loose provenance to Herbert Read. Research for design; research through design; and research about design are shown by Frankel and Racine (2010) to correspond closely with the three categories of clinical, applied, and basic research.

As a designer, process, and its analysis, is integral to the study of cyber-physical systems and their accompanying technologies. Cyber-physical systems are integrated wholes that consider the multiplicity of intersecting feedback loops traversing computation hardware and software, telecommunication, and physical bodily and environmental processes. Understanding these cyber-physical systems in their real-world operation world is essential for industrial design. In order to make designs, design processes, and foster new understandings of design that are both robust and real-world relevant, I have conducted an industrial design practice-led investigation of what in the design world has been termed a “wicked problem”. As Conklin[5] has suggested, a wicked problem is a problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize[i] My wicked problem, that has guided both my design process and my academic and field research, is this: How do we give paramedical care from a distance? My response to this problem has led me to embrace actor-network-theory (ANT) in my industrial design research practice.

ANT, however, is less a full-blown theory than an approach amenable to the vagaries of practice-led industrial design research. As explicated by Annemarie Mol:

> ANT is not a theory. It does not give explanations, and neither does it offer a grid or a perspective. Since “ANT” has become an academic brand name, many authors start their articles with the promise that they will “use actor-network theory”. Let me disappoint them: this cannot be done. It is impossible to “use ANT” as if it were a microscope. “ANT” does not offer a consistent perspective. The various studies that come out of the ANT-tradition go in different directions. They do different things. [6]

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[5] Conklin, Jeff; Wicked Problems & Social Complexity, Chapter 1 of Dialogue Mapping: Building Shared Understanding of Wicked Problems, Wiley, November 2005.

[6] Mol, Annemarie. Actor-network theory: Sensitive terms and enduring tensions. Kölner Zeitschrift für Soziologie und Sozialpsychologie Vol. 50 no. 1. 7. P261

With this understanding of both the problem and the approach in mind, this chapter begins by setting the industrial design challenge. It describes the research objective: to deliver an embodied cognition-based human-mediated teleparamedicine design.

Following this general, subsidiary, and secondary research questions ask a) how teleparamedicine design processes might be instantiated; and b) how ANT might play a role in the industrial design of cyber-physical systems for the context that I delineate as my real-world design terrain: the practices of teams of paramedics and search-and-rescue technicians who use combinations of ambulance, airplane, and helicopter transport in specific chemical, biological, radioactive, nuclear and explosive (CBRNE) scenarios. The context for this teleparamedicine research, who this research is for, and reasons why this research is needed are also given.

1.1: What is teleparamedicine

The term "teleparamedicine" describes paramedical interventions that enlist hospital-level medical staff and equipment remotely through electronic communication. Teleparamedicine involves paramedics and other first-responders, dispatchers, physicians, semi-autonomous medical and telepresence technologies, and patients and their families. Teleparamedicine is often conducted in hazardous conditions. Pathogens and toxic substances, cumulative physiological and psychological stressors, and acutely ill persons may all be present in the moment the teleparamedic is needed. Meanwhile paramedics are busy employing medical instruments, telecommunication devices, and computers in the field, in response to an emergency situation. Emergency transport by ground, air, or water is frequently involved.

Teleparamedical responders must balance and make quick decisions based on each situation's seriousness, available expertise and equipment all the while considering response team safety. Such "equipoise" attends to the emotional, moral, intellectual, social, political, legal, ethical, or social dimensions of bodily and technical phenomenon: what is vital is that the decision does not compromise patient care or place paramedics at inordinate risk.

1.2: Ethnographic observations on site

My explicit and implicit ethnographic observations occurred through my parallel academic and professional research participation in and among academic, commercial, and government settings and participants. That began upon my entry to academia in 1998. My earliest formal design work, internships, and assistantships in institutional and academic research labs began in 2003, in the GF Strong Rehab Hospital, Neil Squire foundation, and the New-Media Innovation Center research labs. This acquainted me with a diversity of research strategies and tactics, and introduced the possibility of research as a subset of design.[7]

Upon commencing my PhD research my approach to field ethnography has had two branches: first, those paramedics, physicians, and the British Columbia first response communities who practiced germinal and rudimentary forms of teleparamedicine; and second, with researchers in academia and industry who have

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[7] Glanville, Ranulph. Researching Design and Designing Research, Design Issues volume 13, Number 2. 1999.

demonstrated expertise in research design. I began with interviewing eight Canada Research Chair holders in a variety of topics and then five Hexagram researchers. In these semi-structured interviews my first line of questioning in was “What is good research?” These questions were framed in terms of research design and instrumentation. The line of inquiry began with human-mediated teleparamedicine processes generally, then narrowed towards a discussion of instances where a research platform with WEHST-like capabilities may be relevant to their specific areas. My early orientation towards researchers as clients also allowed me to approach researchers as neophyte designers who learn by doing.

To this end I conducted a series of recorded and non-recorded semi-structured interviews on two topics: the best practices of research into complex phenomena; and the evolution of research technology. This proceeded first as ethnographic observations of Canada-Research Chair holders from 2007 to 2009, with the goal of illustrating the research design orientation.[ii] Later, in January of 2010, I conducted several days of researcher-oriented ethnographic research at the Santa Fe Institute (SFI), in Santa Fe, New Mexico.[iii]

<u>1.3: How interviews differ from other discussions in teleparamedicine design</u>

Paramedic performance during medical transport is the situation my proposed teleparamedicine system and toolset design endeavour to improve. Telehealth, as ‘healthcare at a distance’, involves distributing individual embodiment as bodies, senses, and attention across space and time. Therefore, the patient-paramedic-physician relationship during emergency critical-care patient transport is becoming the wider medical context of my research. I conducted a semi-structured interview on the topic of emergency critical-care patient transport in July 2008 with Dr. Jeff Plant, Emergency Medicine Specialist at Kootenay Lake District Hospital in Nelson, British Columbia, Canada.[8]

Dr. Jeff Plant describes critical-care patient transport among hospitals striving to coordinate specialized medical capabilities, emphasizing that paramedic-led emergency patient transport processes are becoming more "distributed". That is, a single patient's care increasingly involves coordination among multiple regional health centres. From his point of view, this system is "entropic".

> So the universe is definitely heading towards a higher degree of entropy. That's without a doubt. By cutting rurally particularly, and centralizing all the specialities and subspecialty services centrally, they're developing – probably inadvertently – a more complicated system with more providers, and more chefs in the kitchen. (Dr. Jeff Plant, July 29, 2008)

Teleparamedicine has enabled pre-hospital diagnosis in most of British Columbia, a departure from the basic life-support model that was practiced. Presently most calls ensure a basic level of service while paramedics drive or fly the patient to the nearest hospital. Pre-hospital interventions with advanced procedure or drugs are rarely possible rurally. Dr. Plant describes a "pre-hospital paradox" which has the least-trained, least-equipped paramedics who are working rurally where they potentially have hours of patient transport. Equivalently acute patients in the city have the best-equipped, best-trained advanced life support (ALS) or critical care transport (CCT)

[8] The interviewees' words are transcribed exactly as recorded and are entirely unedited.

paramedics where transport times are 20 minutes or less.[iv] Enabling early intervention by rural paramedics during long transports may reduce patient mortality and morbidity.[9]

My research meets new telehealth requirements to quickly and easily translate patient data into electronic health records (EHR's). Helping paramedics and specialists generate, review, share, and store records supports patient assessment and care during transport allows human-mediated teleparamedicine and WEHST to both track and promote information exchange. This has the potential to effect change across multilevel systems, by expediting the actual transfer of patients to where they need to be for definitive treatment. Plant describes the need for new modes of information exchange to connect those involved in the decision-making and administration.

> So we swim between the middle layers – back and forth – but we never reach the top layer – they are well insulated. In fact I don't know that they actually know what's going on. In my direct negotiations with upper layer they have no idea what's going on. They're insulated from the day-to-day mechanics. (Dr. Jeff Plant, July 29, 2008)

Better telehealth support of (and occasionally triage for) paramedics in the field may include developing a system of regular educational meetings and simulations. Reproducing real-world conditions promotes learning and understanding by teams of trainees including paramedics *and* specialists *and* administrators *and* trainers. Similar to pilot's practicing on flight simulators, running whole teams through life-saving scenarios will prepare everyone. Plant conveys the how emergency physician life-and-death decision-making processes are negotiated. As he says they are "unbelievably difficult". He says,

> Particularly here in BC where the bureaucratic model of a hugely thick middle – translates to patient transfers, so we have multiple phone calls to make with multiple

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[9] Biewener, Achim MD; Aschenbrenner, Ulf; Rammelt, Stefan MD; Grass, René PhD, MD; Zwipp, Hans MD. Impact of Helicopter Transport and Hospital Level on Mortality of Polytrauma Patients. Journal of Trauma-Injury Infection & Critical Care: January 2004 - Volume 56 - Issue 1 - pp 94-98.

agencies – and no-one seems to take ownership of the patient and streamline them from presenting hospital to ultimate destinations. It's so incredibly difficult, because there's a very determined reluctance to change within the administrative structure. (Dr. Jeff Plant, July 29, 2008)

Here good administration and supervision in the system is vitally important. Telehealth includes pedagogy that connects the field in real-time back to a trauma centre to help patients and care-givers. Specialists are repeatedly called *into* the field from multiple emergency rooms by paramedic colleagues lacking training, experience, or confidence in specialized aspects of emergency medicine. Giving supervision is essential to a specialist physician's informal job description. Mentorship hinges on the rewards of watching over colleagues and seeing their confidence grow. Physicians or paramedics benefit from someone there with them. Remote supervisors coach them along and in Dr. Plant's words say, "Just take your time and do this. I'm here for you if you need." Whether in-person or through an in-field mediator and remote supervisor, going through life-or-death situations is valuable for patients and paramedics, Dr. Plant asks us to consider how teleparamedicine actants share responsibility for practice, pedagogy, and research.

Figure 1.1: Teleparamedic mediation gives remote physicians first-person views of, and embodied care for, patients; and offers patients human embodied care by remote physicians. Paramedics themselves are also mediated *by* and *among* patients, paramedics, and WEHST.

1.4: WEHST- the answer

In response to this multiplicity of challenges, identified through ethnography, interviews and observation, this dissertation proposes a new technology: a paramedic-worn toolset I term a "wearable engine for human-situated telepresence" (WEHST). WEHST is a platform technology, a mobile multi-agent system of paramedic-wearable telerobotics. WEHST is worn on the body. It thus couples closely and intimately with paramedics via its sensitive personalized and situated feedback capabilities that measure a variety of bodily signals. WEHST is essentially a platform technology comprised of variously connected wearable components that are usable with *existing* uniforms and harnesses. WEHST is modular and can be integrated into uniforms made of layers of woven and laminated textiles. It can be arranged as single-function accessories carried in pockets. It is adaptable and can situate itself into many different existing wearables. To date, I have developed eight families of modular electronic black boxes built on a square grid of exponentially increasing increments of 1, 2, 4, 8, 16, 32, 64, 128 and 256 mm on X and Y axes, with Z axis height advancing in approximately 1mm increments. The eight families are named by function in table 1:

Table 1.1: WEHST's eight modular families and their naming scheme

Family*	Role
COMmand	This telepresence gatekeeper module apportions multilateral communication and control between remote supervisors, paramedics in the field, the wider wearable WEHST montage, and the limited artificial intelligence of the COMmand module.
HUB	The HUB physically integrates power transmission, wired and wireless data transmission, electromechanical coupling, and electrical isolation among modules. The HUB provides a "heartbeat" signal tightly synchronizing a WEHST montage.
MEDia	Telepresence media production and playback configurable as wearable videoconferencing.
MEMory	Data buffer, storage, cataloging, and retrieval.
POSition	Macro-environment, garment microclimate, and near-body sensing/feedback.
POWer	Power modules are hot-swappable and allow the reloading of batteries without shutting down.
PROcessing	Signal-processing capabilities, including computer vision, data compression, signal conditioning, encryption, and types of artificial intelligence.
PSYchophysiology	Detects, monitors, enables feedback and feedforward, and manages physiological body signals.
* In this thesis I do not shorten the names to COM, HUB, MED, MEM, POS, POW, PRO, and PSY. However, the names of the device classes themselves require a visual cue (in this case capitalization of the first three letters of a colloquial title) to distinguish them as components of the WEHST product system, and not be read out of context.	

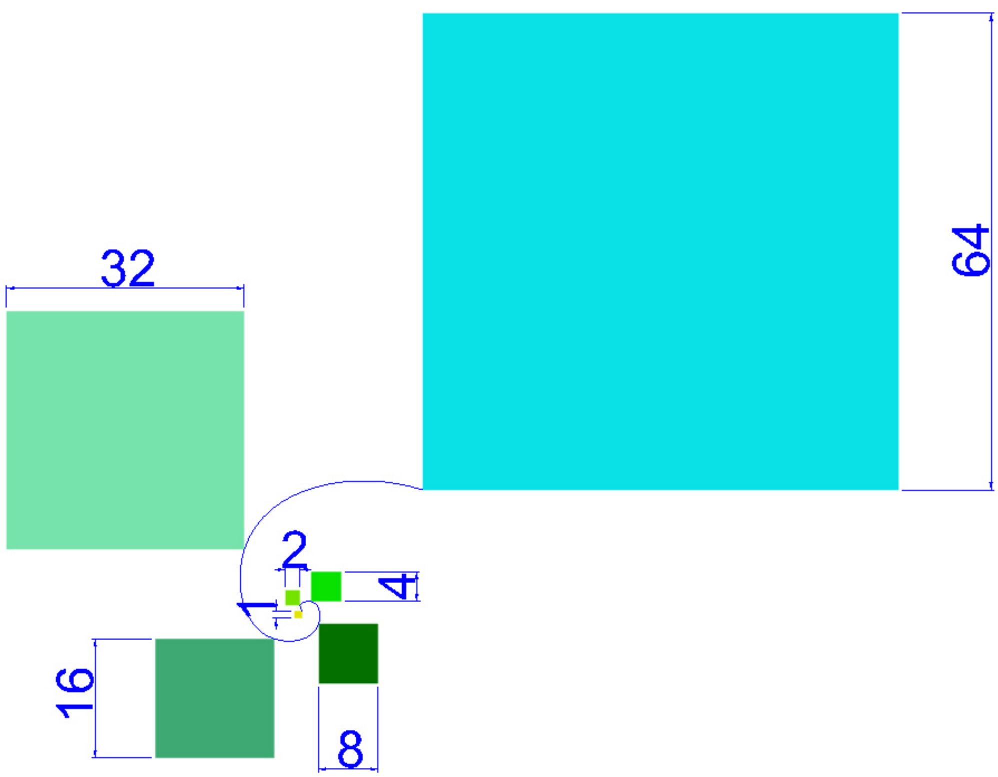

Figure 1.2: CAD rendering shows grid of boxes

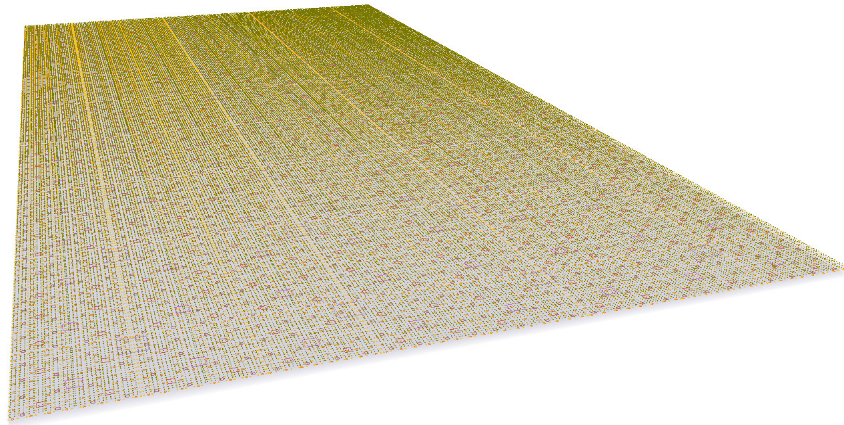

Figure 1.3: Conductive weave structures may form points of connection at various depths and positions corresponding to WEHST connector lengths and diameters.

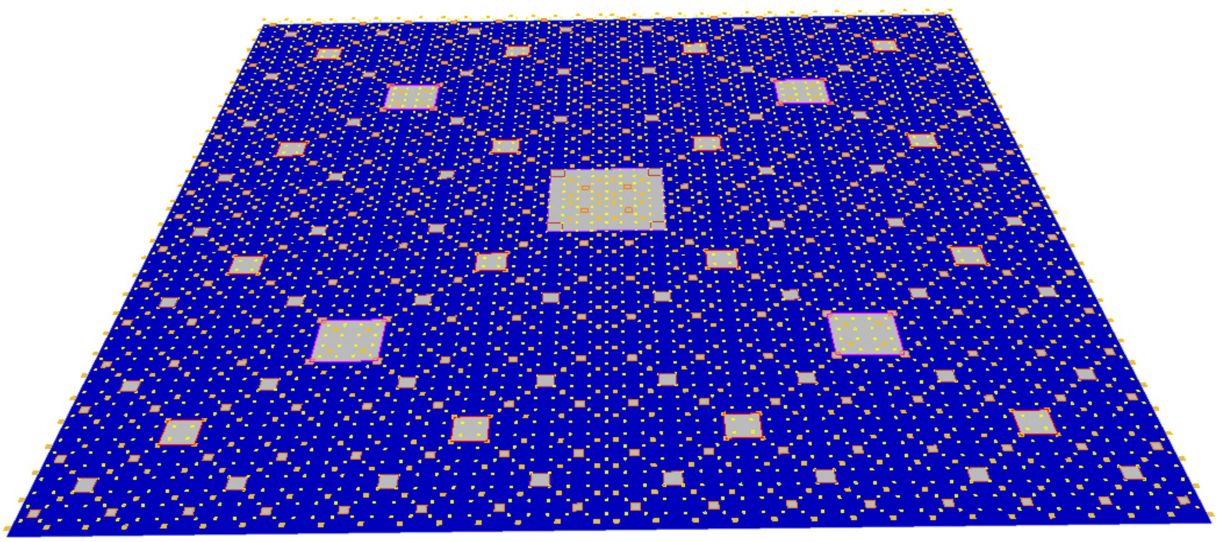

Figure 1.4: Conductive pad target zones corresponding to WEHST module patterns of gradations.

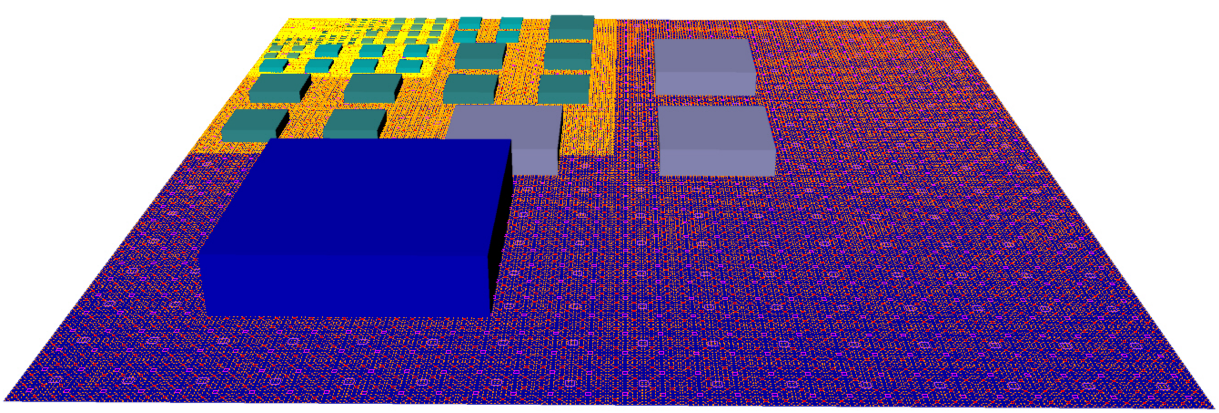

Figure 1.5: CAD rendering shows grid of boxes plus electronic textiles.

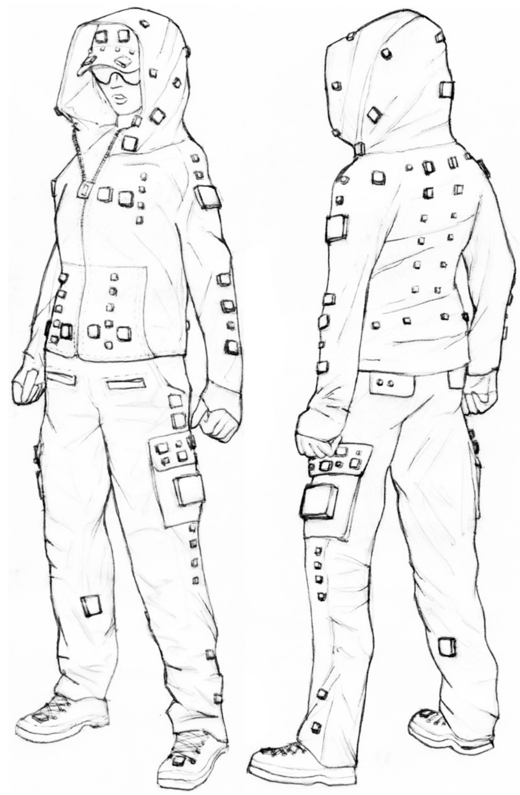

Figure 1.6: This illustration shows two views of a WEHST montage on a paramedic. Thousands of basic combinations of WEHST are possible to fit bodies, environments, and scopes of practice.

The WEHST design is a ‘Lego-like’ toolset. WEHST is comprised of: colour-coded interlocking composite bricks of metal, plastic, electronic components, insulators, connectors, and sensors and effectors; textile substrates; and an array of peripheral sub-systems from various other commercial vendors. WEHST ‘bricks’ can be assembled and associated in numerous ways to construct wearable telepresence instruments. If required, any WEHST assemblage that is constructed can be partly or fully disassembled again. The modular components can be used to create other WEHST assemblages. WEHST’s interlocking boxes are developed from contemporary stackable electronic connectors, printed circuit boards, and integrated circuits that are fashioned into blocks that lock together in an array of multiple sizes. It uses interpolated male and female conductive pins and a small number of machine screws to hold together. These blocks of various size gradations employ multiple overlapping grids of electrical and mechanical fasteners to interlock at large or small scales.

WEHST assemblages are a telepresence cyber-physical system for clinical practices, teaching and learning, new knowledge creation, and creative play. However, the technical limitations of ensuring both secure attachment and flexible positioning demands the creation of a product line with a range of box sizes varying in width, height, and depth in 1mm increments. Larger sized boxes integrate more diverse or advanced capabilities. This approach enables releasing new components iteratively – along with new software and middleware applications – without compromising the performance of proven assemblages. Sold or distributed as sets of boxes, WEHST promotes reconfiguration to match the variety of complementary or competing technologies and practices presently (and prospectively) employed by clients.

Other interface elements may interlock with sets of WEHST boxes to fit the requirements of end-users. The scalability of the design allows WEHST's range to be expandable so that it may incorporate other small or large accessory boxes with ever-more complex or necessary electronic, mechanical, chemical, or biological components. It all depends on the situation and the use being forecast. New styles of interlocking connections are iteratively introducible and are compatible forwards and backwards with preceding and succeeding types of connections. A highly flexible and modular system, WEHST's interlocking architecture ensures that individual pieces may change purposes among clients and across time. The degree of precision WEHST is manufactured to is not uniform, as each scale of grid requires its own tolerances. Particular applications may require several to several thousand assembly-disassembly cycles before breaking down.

These ensembles of programmable WEHST boxes configured as wearable toolsets are instances of mobile cyber-physical systems, in which the physical system of paramedic bodies and WEHST-based wearable toolset are inherently mobile sensor-based multi-lateral communication-enabled autonomous systems. They can be thought of as wearable “robots” which may monitor themselves and their environments and relay the processed information to remote specialists. In teleparamedicine practices, where rapid adaptation is essential, actants of all types share in the dynamics of these cybernetic processes that use combinations of analog and digital computation, networking technologies, software models and languages, and concurrency mechanisms. These feedback processes extend across physical dynamics such as biomechanical, physiological, psychological, and environmental processes. All need to collaboratively allocate responsibilities among the interlocking physical components and software.

1.5: Why WEHST?

The proposed WEHST system is a scalable series of interconnected boxes adaptive to the interplay of ergonomic limitations and environmental perturbations degrading paramedic or tool performance. For example, at certain critical junctures control by manual triggering, voice-activation, or speech recognition is not possible. How then to act? COMmand, one of the WEHST modules I have designed, permits hands-voice-speech-free telepresence control of personal radios and telepresence-related equipment. The complexity of the situation faced by the resultant hybrid actor at work within this situation is irreducible. However, taking teleparamedicine complexity as the norm permits applying complex adaptive systems[10] principles towards translating this complex design problem into a correspondingly flexible and adaptable wearable engine for telepresence- and good decision-making in the field. Situating paramedics amid an engine of interoperable semi-autonomous WEHST modules embeds them in a composite teleparamedicine architecture spanning heterogeneous teams, sites, participants, and scales.

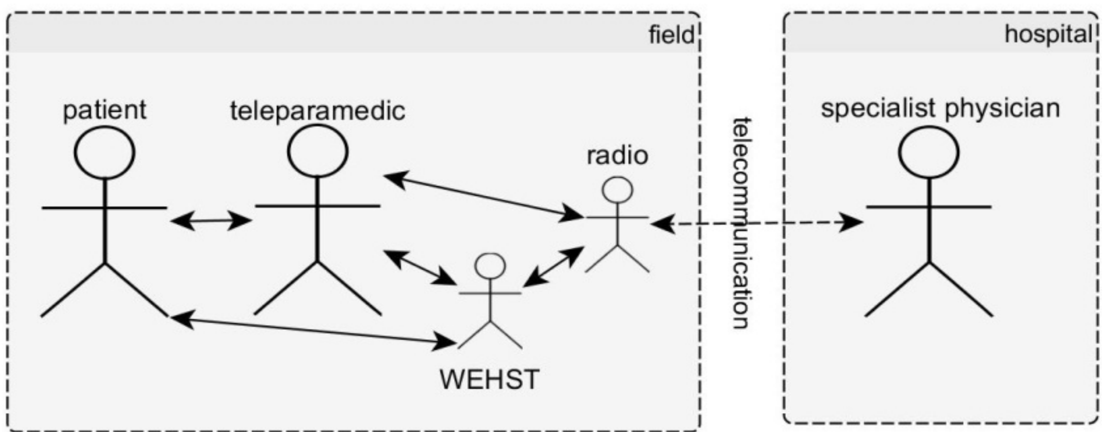

Figure 1.7 Diagram shows human-mediated teleparamedicine (HMTPM) black-boxing.

[10]Holland, John H.. Signals and Boundaries: Building Blocks for Complex Adaptive Systems. MIT Press. Cambridge, Massachusetts. 2012. P7

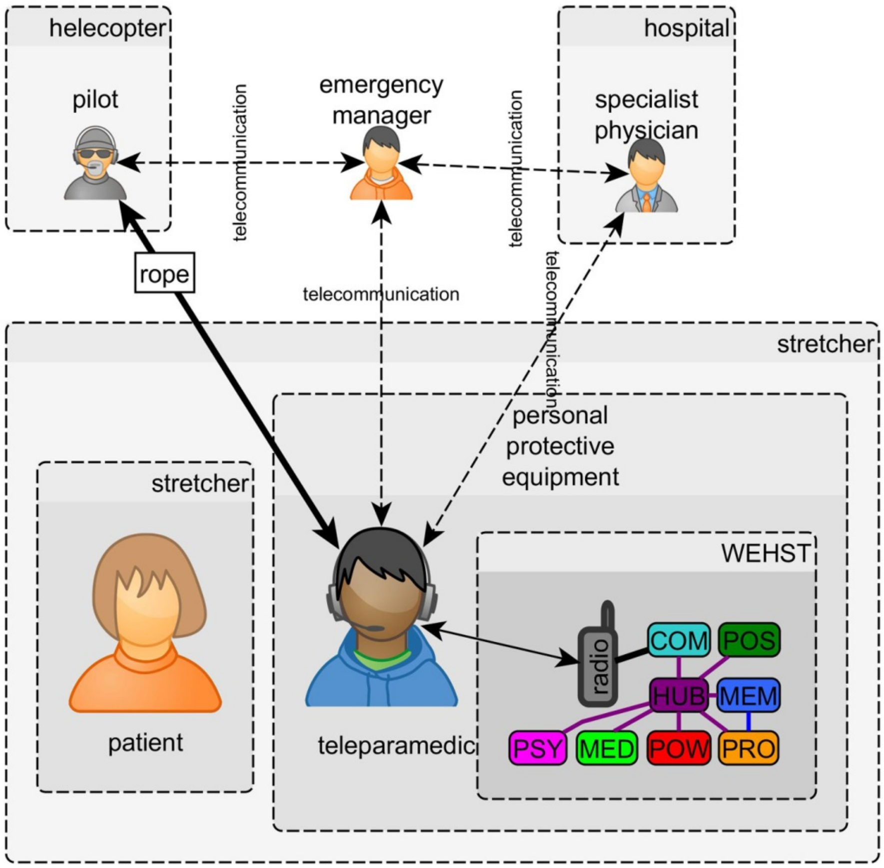

Figure 1.8 Illustration COMmand and radio on body during SAR rope rescue in CBRNE PPE, HETS with a stretcher below helicopter.

The WEHST design is a multilateral carrier for human-mediated teleparamedicine signals.[11] As I argue through my creative practice as an industrial designer, and through the production of a system like WEHST, the technical, ergonomic, economic, ecological, and ethical feasibility of human-mediated teleparamedicine necessities something like WEHST as a mass-manufacturable and mass-personalizable fabric substrate for wearable computing-based toolsets in emergency situations. WEHST design stitches together separate human, technical, and ecological actors into intimately connected assemblage of actants.

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[11] Haikonen, Pentti O. Robot Brains; circuits and systems for conscious machines. Wiley and Sons, UK 2007. P18

Taking our human embodied cognition into account, the human-based computation (HBC) processes materialized in WEHST's systems architecture apportion an individual paramedic's physical, cognitive, and economic resources within a set of symbiotic human-computer interactions. The WEHST design is an instance of embodied cognition-grounded wearable robotics that incorporates fluctuating degrees of self-monitoring intelligence. WEHST's distributed computing architecture improves the conditions of its wearers and their associates, including their protective garments and tools at hand, as well as the telecommunication networks within ambient environments that are monitored by the WEHST system's sensors. This form of embodied artificial intelligence is conducive to active self-maintenance and self-repairs during assembly or reassembly, or when bent, shaken, stretched, frayed, torn, or broken during normal wear.

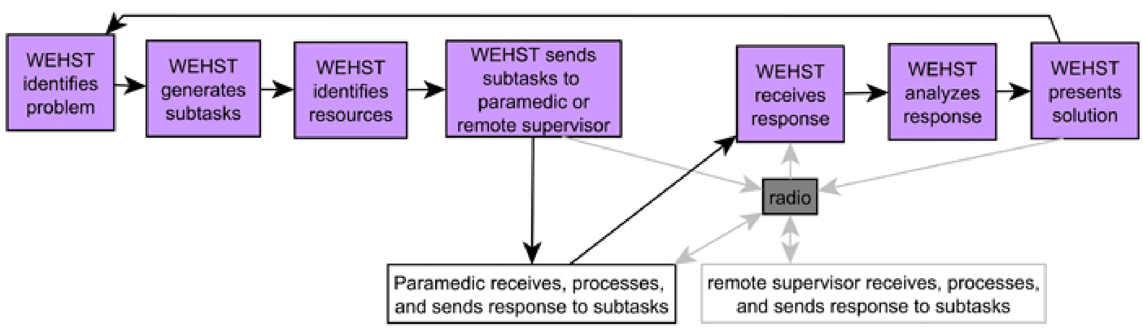

Figure 1.9 human-mediated teleparamedicine uses WEHST-based human-based computation (HBC).

WEHST is an industrial *design* response, the material artefact that is the result of my primary research question: how does one design a 'piece' of wearable telepresence technology for paramedics working in extreme situations? Cognizance of the embodied, distributed, and processual character of computational textiles, honed through my reading of ANT and ethnographic approaches, has been my guide.

Subsidiary questions that follow the creation of WEHST include: how does this object need to be designed to safeguard paramedic safety, autonomy, and performance? How does this object/assemblage collect and convey multimedia medical records of *and* for patients and paramedics in the field during remote telehealth supervision by specialists? In this way, I ruminate on theoretical questions pertaining to actor-network theory and its potential contributions to design processes and products, taking as a point of departure my own design work.

1.6: The Quest for WEHST as Research-Creation

Such research, itself ensconced in what has come to be known in academia as “research-creation” emphasizes that making, doing, and theoretical reflection are needed to improve patient care in extreme situations. My research-creation project uses multiple methodologies. First, I use mixed structured and unstructured interview techniques throughout field ethnography within the British Columbia first-responder community. Understanding participants’ unique relationships to their bodies, tools, peers, and environments is paramount.

Second, my professional industrial design research practices within medical instrument research and development laboratories extends the scope of my project to include an understanding the needs and capabilities of those stakeholders who are “upstream” from field practice. Extensive experience with technical and regulatory standards, manufacturing capabilities, and norms of market-driven research and development practices are also informative.

Third, my academic research is conducted through close reading of, and commentary on, theoretical and technical literature applicable to teleparamedicine and WEHST design.

Fourth, my personal industrial design studio work involves sustained research-creation (R-C) processes of configuring off-the-shelf technologies to address human, technical, and ecological needs identified by field, laboratory, and academic arms of my research.

Research-creation encapsulates my multiple individual and team-based projects intersecting “theoretical, technical and creative aspects.” This sustained research enterprise is guided by broad objectives for advancing knowledge in industrial design, through developing research instrumentation renewing the rigor of basic, applied, and clinical research and research-creation in the design field (refer to Appendix 10.5 for a brief overview of pertinent research creation projects).

These endeavors correspond with Chapman and Sawchuk’s discussion of research-creation as a series of inter-related instances that constitute a set of ‘family resemblances’’. *Creation-as-research* proceeds as a continuous industrial design production of physical prototypes, drawings, diagrams, and intellectual property documentation. This studio-based production is in tandem with my ethnographic research and surveys of ANT-related literature. As Chapman and Sawchuk explain “Through research (i.e., interpretation, analysis), through creation (i.e., deployment, hands-on engagement), the very phenomena we seek to explore are brought into being in the first place.[12]

"At what point does an idea become a 'thing'?"[13] My creative practice embodies designs for tools reciprocally and continuously refining the research itself. A continuous becoming of teleparamedicine 'things' occurs as essays, sketchbooks, CAD files, commercial prototypes and products, and neurophysiological processes accumulate, aggregate, and accrete.

"Is this creation?" My research has from the beginning explicitly sought to develop a product system that does not yet exist. While teleparamedicine technologies exist now 'on the shelf' these materials and components are either too immature or too poorly understood to integrate into product systems. Avoiding reductive approaches to the complex technologies and relationships implicit in experiences of, and transformations in, human-mediated teleparamedicine requires intuition and aesthetic intelligence. Creativity is required to guide continuous revisions and refinements of the integration of disparate research and design elements.

Chapman and Sawchuk ask "What are the different ways the reality can be 'enacted'?" Their discussion of research-creation fits my practice of engaging directly with medical practitioners and academic researchers whose work hinges on human-mediated teleparamedicine processes becoming materialized. These proposed product systems' commercial feasibility is refined through reflection *and* peer engagement.

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[12] Chapman, Owen and Sawchuk, Kim. Research-Creation: Intervention, Analysis and Family Resemblances. Canadian Journal of Communication Volume 37, 2012. Canadian Journal of Communication Corporation. P6
[13] Chapman and Sawchuk. 2012. *Ibid.* P21

1.7: Reflexive design and Real-World Extremes

In addition to situating my work as a research-creation project, I am indebted to understandings of design as recursive and reflexive. In so doing, I am designing tools for research design and design research that is technically and ethically constrained by the needs of the most vulnerable and dangerous group of real-world design participants I could readily identify: teleparamedics working in situations of extreme risk and danger.

Proposing partial autonomy, self-tracking, and situational monitoring capabilities as ethical design prerequisites is also a critique of the risk-aversion endemic to many professional industrial design communities who only work in laboratory settings. This is related to a consideration of the role of technology-creation as a part of the dilemma of industrial design. Hans Jonas suggests that

> By the kind and size of its snowballing effects, technological power propels us into goals of a type that was formerly the preserve of Utopias. To put it differently, technological power has turned what used and ought to be tentative, perhaps enlightening, plays of speculative reason into compelling blueprints for projects, and in choosing between them we have to choose between extremes of remote effects. The one thing we can really know of them is their extremism as such – that they concern the total condition of nature on our globe and the very kind of creatures that shall, or shall not, populate it. In consequence of the inevitably "utopian" scale of modern technology, the salutary gap between everyday and ultimate issues, between occasions is closing. Living now constantly in the shadow of unwanted, built-in, automatic utopianism, we are constantly confronted with issues whose positive choice requires supreme wisdom.[14]

As Frankel and Racine observe: "There is no single common definition of design and some definitions even seem to contradict each other."[15] My research in industrial design emphasizes practices that incorporate a reflexive approach to technology and

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[14] Jonas, Hans. Philosophical Essays: From Ancient Creed to Technological Man. Chicago: University of Chicago Press, 1974. P241

[15] Frankel, Lois and Racine, Martin. The Complex Field of Research: for Design, through Design, and about Design. Design Research Society International Conference 2010. Design and Complexity conference proceedings. Université de Montréal, Canada. P3

technological systems. Working within this ambiguity, my focus on teleparamedicine, from a reflexive design perspective, aligns with Hans Jonas's insistence that human survival is dependent on caring for our future selves, our companion species (Haraway's term) and companion technologies, and our companion (planetary) ecologies.[16]

My focus on reflexive design for real-world extremes of human, technological, and ecological inter-species aims to produce hybrid technologies that scale up to the task of addressing vast problems that often outstrip our means to understand or describe them. Computational textile[v] conduits connect the potential stakeholders of my wearable telepresence research program. WEHST embodies just one intimately situated layer of multi-scalar fabric computing by creating a computing fabric that concretely and figuratively connects human-mediated teleparamedicine actants. Teleparamedicine phenomena are conceptualizable as the very fabric of these actants who are interconnected and widely distributed in space and time.

1.8: Why Paramedics?

Paramedics push the physical, technical, and environmental boundaries of telepresence and telehealth by acting in delimited teleparamedicine contexts. This is one reason that I generally sought out paramedics in search and rescue (SAR) settings qualified as helicopter external transportation system (HETS) operators. Paramedics operating helicopter external transportation systems during search and rescue must

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[16] Jonas. Philosophical Essays. *op. cit.* 1974.

counterpoise safety of themselves, against safety of their teammates, patients, and equipment. Aviation offers a highly constrained physical environment and hyper-vigilant safety culture, so I also interviewed paramedics qualified as paratroopers or with extensive airborne patient transport experience. To plausibly narrow this context further, I contextualized my research with the practices of paramedic responders in challenging chemical-biological-radiological-nuclear-explosive (CBRNE) teleparamedical situations. This setting defines conditions where every designer, designed tool, scope of practice, and team of paramedics will always fail to some degree. These are conditions where design success is not as simple as pass/fail, and remains always partial and perennially complex. It is in this site that my ANT-grounded industrial design research is situated.

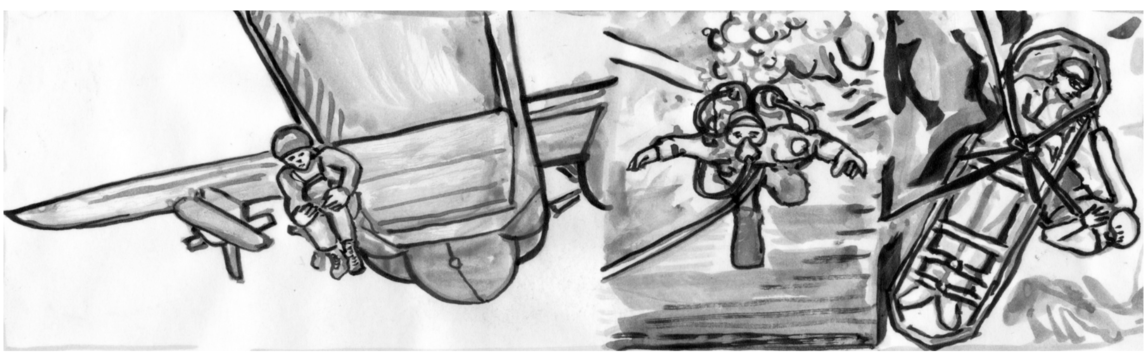

Figure 1.10 Canadian mountain search-and-rescue is conducted paramedicine in air, water, and mountain settings.

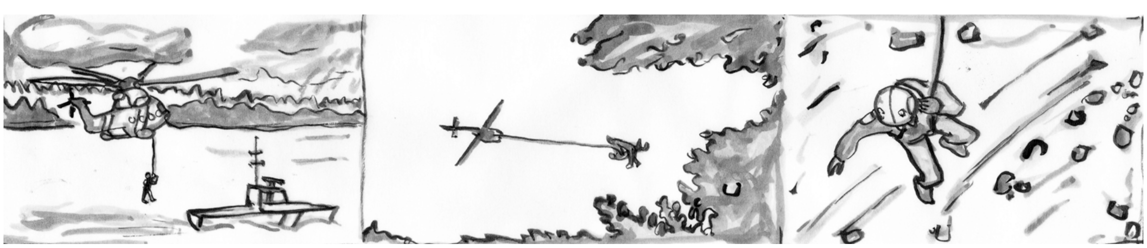

Figure 1.11 Helicopter External Transport (HETS) operations practically and legally make the paramedic (and the cable suspending them) part of the helicopter airframe.

Figure 1.12 Chemical-biological-radiological-nuclear-explosive (CBRNE) response teams wear cumbersome personal protective equipment (PPE) which induces intense physiological stress.

Translating existing “surveillance”, “sousveillance”[vi] and “equiveillance”[vii] technologies into a confluence of novel, useful, and non-obvious areas of possible research is how I came to create my human-mediated teleparamedicine system. Teleparamedicine helps remote medical specialists increase the scope of care of patients *and* paramedics *and* wearable robotics.[viii] This actively assists paramedic practices with paramedic-worn videoconferencing systems by providing specialized pre-hospital telehealth services on behalf of distant physicians via mobile telecommunication networks. These partially autonomous tools interleave biometric, technological, and environmental sensor and effector capabilities. This enables inter-modal correlations supporting paramedic communication, diagnostic, monitoring, and therapeutic practices, while augmenting clinical research into paramedicine.

Reciprocally, these practices are a basis for basic and applied research into computational-textile-based telehealth. WEHST is a teleparamedical assemblage, a technology that is in situated semi-autonomous wearable computing platform adaptable to basic, applied, and clinical research.

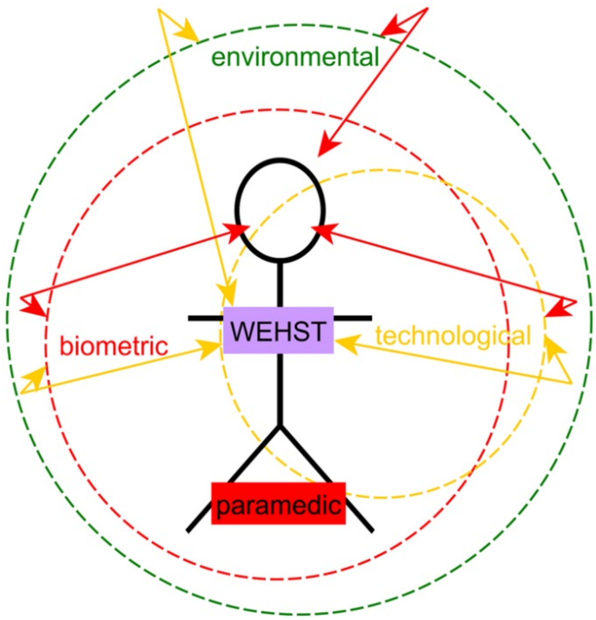

Figure 1.13 WEHST is an instrument enhancing paramedic performance via biometric, technological, and environmental sensing and feedback.

“WEHST”, my primary research outcome, is meant to improve the search and rescue paramedic mediation of telemedical supervision by remote specialists in the course of patient care in chemical-biological-radiological-nuclear-explosive settings. The mediation capabilities of paramedics and their telecommunications tools are augmented by enabling novel modes of two-way multimedia telepresence production. To give a few examples of their application, enhanced communication may support remote specialists teaching paramedics on-the-fly. All manners of communication among paramedics in hazardous environments present degrees of cognitive, affective, and physical difficulty.

WEHST addresses the need for practice-based communication to continuously safeguard against, or remedy, insults and injuries. Most critically, teleparamedicine capabilities must be interoperable with panoply of body-proximal uniforms and paramedic personal protective equipment (PPE). An abridged roster of wearable or portable material includes various classes of chemical-biological-radiological-nuclear-explosive protective suits, filtration respirators or self-contained breathing apparatus (SCBA), helmets, gloves, goggles, tool belts and harnesses, decontamination equipment, and vehicles.

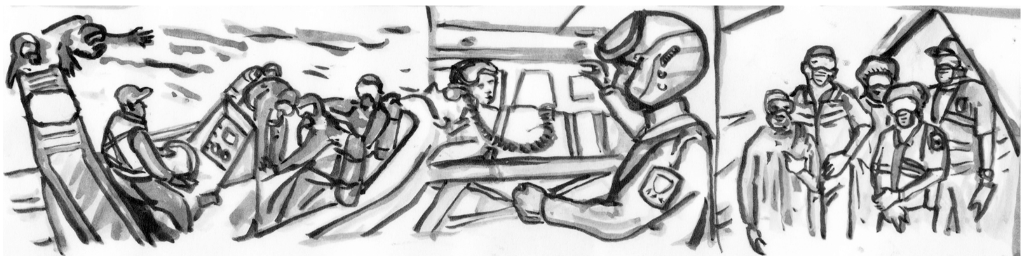

Figure 1.14 Personal protective equipment (PPE) is ubiquitous to search-and-rescue, paramedicine, and chemical-biological-radiological-nuclear-explosive response

Wider beneficiaries of teleparamedicine-supported rapid consultation with remote specialists (and the concomitant augmentation of paramedics' scopes of practice) include all members of civilian, volunteer and military organizations with paramedicine and telehealth mandates. Beneficiaries also include care-givers in clinics or hospitals performing remote tele-consultations, and rescuee's receiving care in hazardous situations.[ix]

Figure 1.15 The British Columbia Ambulance Service work with land, air, and sea-based patient transport challenges. They operate in circumstances spanning extreme poverty and privilege; are confronted daily by disparities in care with racial overtones; and navigate the contrast between concentrated and largely centralized urban coastal populations and vast (and inaccessible if the weather is inclement) rural reaches interspersed with small population centers.[17]

[17] http://www.bcas.ca/. Downloaded November 12, 2014.

Figure 1.16 Extreme geography combined with advanced medical capabilities makes all paramedicine trades of the British Columbia Ambulance Service into telehealth innovators and early adopters.

Paramedics qualified for high-risk environments are well positioned as informants and co-design participants. The approximately 45 paramedics I interviewed (of whom the stories of five paramedics are directly presented in this dissertation) aptly guided my industrial design of robust computational textiles by sensitively describing how their quotidian practices already combine and integrate physiological, electronic digital, electronic analog, analog, and human-based computation – and what usability my design would need. Paramedics' nuanced sensory, cognitive, and physical ergonomics guided my computational textiles design. Their comfort, hygiene, and personalization encompass specific individual and general community needs. These teleparamedicine experiences are transferrable into other settings where users have less-acute design constraints.

Balancing WEHST computational textiles cost in relation to durability, serviceability, and disposability makes paramount their capabilities for technical hardware and software adaptation that is concurrent with use. WEHST has been, and will be, continuously re-evaluated to match changing regulations, industry standards, best-practices, complementary tools, emerging technology platforms, and incipient workplace biohazards. Paramedics' quintessential role in shaping the fit and feel of computational textiles arises from their requirements for extreme mobility and wearability in diverse environments. Furthermore, paramedic's operate in urban, rural, residential, commercial, and industrial environments that are brimming with actors. Paramedic's in-transit via ambulance, boat, hovercraft, airplane, or helicopter are pressed into close association with myriad onboard technical actors and teammates, to form numerous communities and situations. Paramedics also circulate continuously through hospitals and clinics placing countless populations into a host of distinct medical communities linked in part by patient transport services.

Figure 1.17 British Columbia Ambulance Service conducts inter-region, intra-urban, and inter-urban patient transport.

1.9 Reflexive research through the design of research design tools

My project-grounded research can be positioned as applied research through design. Adopting an action-reflection approach[x18] creates new knowledge of ANT-based design specifically and process-philosophy-led practice generally. Human-mediated teleparamedicine systems and WEHST toolsets embody ontologies of *becoming*, whereby changes in paramedics, tools, and environments are concurrent with normal operations and may be intentional and welcome. ANT guided human-mediated teleparamedicine and WEHST systems-level design extends processual thinking within

[18] Jonas, Wolfgang. Design Research and its Meaning to the Methodological Development of the Discipline. In R. Michel (Ed.), *Design Research Now*. Basel: Birkhäuser.

real-world practices. The premised non-local and non-unitary practices, tools, and people are technically achievable and ecologically desirable. Despite design's close association with human-centred methods,[19] research through design does not preclude projects grounded in explicitly heterogeneous and ecosystem-grounded actants.

Deep entanglement across categories is neither anthropocentric nor subscribing to a reductive philosophical anthropology. I draw a distinction between human-centered and human-based design. Somewhat more than human-centered design, the symmetries of research through human-*based* design[xi] deliver robust human-based computation and offer technical and behavioural pathways to ecology-based computation. Fundamentally, advancing ecosystem-based perspectives on, and practices of, research design and research instrument design is through grappling with phenomena of human/AI/ecosystem situated computation.[xii]

As Robin Greely stated in 1998:

> Design as a discipline, therefore, finds itself in the crucial position now not only of organizing information in an ever more sophisticated web of global communications, but also of offering a metacritique of how such information is organized (with all of the content of issues this raises, such as who is allowed to organize it, for whom, under what conditions, and so on).[20]

Latour goes on to define the challenge as such:

> Here is the challenge. In its long history, design practice has done a marvellous job of inventing the practical skills for drawing objects, from architectural drawing, mechanic blueprints, scale models, prototyping etc. But what has always been missing from those marvellous drawings (designs in the literal sense) are an impression of the controversies and the many contradicting stake holders that are born within with these. [21]

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[19] Frankel, Lois and Racine, Martin*, op. cit.* The Complex Field of Research: for Design, through Design, and about Design. 2010. P6-7
[20] Greeley, Robin Adele. Richard Duardo's Aztlan Poster: Interrogating Cultural Hegemony In Graphic Design. Design Issues: Volume 14, Number One, Spring 1998. P21-34
[21] A Cautious Prometheus? A Few Steps Toward a Philosophy of Design (With Special Attention to Peter Sloterdijk). 2008, In Fiona Hackne, Jonathn Glynne and Viv Minto (editors) Proceedings of the 2008 Annual International Conference of the Design History Society – Falmouth, 3-6 September 2009, e-books, Universal Publishers, 2008. P12

I have heeded Latour's challenge in designing WEHST. As reflexive human-mediated research sites and platform technologies, teleparamedicine and WEHST are positioned as innovative tools for tracking and presenting the "contradictory and controversial nature"[22] of things participation in reflexive research design. This is again why ANT has been valuable to this project. Latour emphasizes the gradual emergence of a visual vocabulary as a departure point for novel tools. He proposes drawing things through "visualization" practices tracing their complexity as political processes spanning – and contravening – macro-to-micro ecological scales.

Research for WEHST interweaves telehealth, wearable computing, and industrial design. Adaptive WEHST architectures embrace other designers' continuous innovations across times and locales. Wearable designs such as these provide the parameters to build, conduct, and refine research. This encourages probes, prototypes, trials, and products. Practice-and-project-grounded research through WEHST technology gives designers experience with complex product-systems, design which includes concerns for human-computer interaction, service and manufacturing-oriented electrical and mechanical engineering, and computer science. It can also lead to improving the marketing and economics of social science tools.

In summary, WEHST blurs research and practice. WEHST fits research labs, design studios, bodies, and markets. WEHST is an assemblage that incorporates the politics, aesthetics, and ethics of rapid response and adaptation among counterpoised

[22] Ibid. P13

actants as described by Alain Findeli and Rabah Bousbaci.[23] While Findeli and Bousbaci don't attribute full actorship to non-humans, they helpfully describe the place of ethics in design as a process for both taking projects as intrinsically non-unitary and promoting concord among inherently disparate agendas actors:

> Actors are also, beyond their respective special skills, *practical* persons (praxis), whose actions or speech are aimed at achieving a good life with and for the others. They acknowledge the plurality and otherness of their fellows, within whom each one discloses him/herself by words and deeds. This common representation of the actors as projecting beings brings about new understandings of the two other constituents of the project: the design process and the building. Since the project is, above all, the project of the actors, the entire design process can be regarded now as a federating setting within which all the specific projects of the actors find their expression. If this federating characteristic is to be considered under the lens of ethics, then design process can be viewed as 'a concord of several projects' (a joint project}, i.e. a practical, reflective, and deliberative process.[24]

This leads to WEHST becoming industrial design research tools which are continuously contributing to their own design vocabulary and reflexively shaping the multiple projects and disciplines implicated.

In this chapter, chapter one, I have described my use of multiple methodologies of research-creation, research through design, and ethnographic observation (including how these interviews differ from other discussions in teleparamedicine design) are applied and adapted for this context and situation. In Chapter Two, I zoom in. This Chapter discusses, in detail, what ANT is, why the ANT approach is important to a range of teleparamedicine design challenges, and how ANT has influenced the design of my "object", an assemblage of interlocking components that share biofeedback from the user to other experts located remotely, a system I have built called WEHST: Wearable Engine for Human-Mediated Telepresence. Chapter Three situates WEHST

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[23] Findeli, Alain and Bousbaci, Rabah. More Acting and Less Making: A Place For Ethics In Architecture's Epistemology. Design Philosophy Papers. Volume 3, Number 4, December 2005, P6
[24] Ibid.P6

within other contributions to teleparamedicine designs that operate as competitors or alternatives to my device. This chapter also acknowledges designers who have informed my work. Chapter Four discusses my field research elaborating how I conducted it, and what I learned from observations in field settings, laboratories, studios, and in the literature. Chapter Five returns to my interviews with emergency personnel, explains why I chose these interviewees, and reflects on their advice and observations, which informed the design created for these teleparamedicine personnel. Chapter Six re-examines my industrial design process and summarizes the journey of my process from journals and notebooks, later synthesized into a modular, scalable, adaptable, and decentralized system-architecture, WEHST. This chapter presents the making of WEHST as a system-level design and includes diagrams, illustrations, and 3D-CAD models.

The final chapter, chapter Seven, reflects on the process of human-based computation industrial design and evaluates how my approach contributes to this practice. Chapter Seven begins with reflection on the whole human-based computation industrial design process in terms of ANT-guided design of COMmand to: trace the formation of groups, map controversies over agency, make an object's activity easily visible, and deploy matters of concern. This reflection also addresses how my approach contributes to human-based computation industrial design in terms of how COMmand tracks actor-networks and tracks the production of accounts, and how COMmand cannot deliver face-to-face interactions. This chapter closes with a conclusion of contributions that this project makes to different fields of industrial design, wearable computing, and teleparamedicine. The dissertation closes with a coda describing how the research results correspond to the research objectives.

Chapter Two: Actor-network-theory for teleparamedicine

As mentioned, one of the primary concerns of this project is understanding cyber-technical systems in their complexity. One of the most powerful set of examinations of these systems in contemporary social theory comes from the tradition of what is known as Actor-Network-Theory (ANT) whose main practitioners may include Bruno Latour, often considered the founder, John Law, Lucy Suchman, Annemarie Mol, and Michel Callon.

In a cogent explanation of actor-network-theory, John Law suggests that ANT is a sociology of associations and that the project of ANT is to extend the list of participants in a process, and to understand how together they come to constitute an entity that is materialized.

> The project of ANT is simply to extend the list and modify the shapes and figures of those assembled as participants and to design a way to make them act as a durable whole. For sociologists of associations, what is new is not the multiplicity of objects any course of action mobilizes along its trail—no one ever denied they were there by the thousands; what is new is that objects are suddenly highlighted not only as being full-blown actors, but also as what explains the contrasted landscape we started with, the overarching powers of society, the huge asymmetries, the crushing exercise of power.[25]

Law's pitch of ANT as a material-semiotic toolset for description and "a toolkit in sociotechnical analysis" (Law 2007) is consistent with my own project-led research findings and the impetus behind the WEHST toolset. My proposed WEHST toolset,

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[25] Latour, *op cit*. Reassembling the social 2005. P72.

cultivated in ANT's shadow, has slowly grown into a means for both the tools embedded in the system architecture, and users, to continuously adapt, change, and redefine system-level goals.

Law gives ANT four qualifications. His first rejoinder is that ANT is a practice of "empirical case studies". This makes abstract descriptions of ANT extraneous to understanding ANT's "empirically-grounded practices." Second, Law explicitly qualifies ANT as not a theory, but rather as an approach. As a tactic – an approach – to analyzing networks and systems,

Distrust of unitary perspectives is perennially relevant for any technologies. ANT is premised on surprisingly supple and endlessly messy material-semiotic bodies:

> "[A]ctor network theory is descriptive rather than foundational in explanatory terms, which means that it is a disappointment for those seeking strong accounts. Instead it tells stories about "how" relations assemble or don't. As a form, one of several, of material semiotics, it is better understood as a toolkit for telling interesting stories about, and interfering in, those relations." (Law 2009, P141-2)

ANT broadens, subverts and remakes methodologies. ANT prescribes "sensibility to materiality, relationality, and process." (Law 2004, P157) ANT relationalities inculcate suspicion toward sweeping social theories offering reductive explanations.

Third, Law qualifies ANT as an affiliation of material-semiotic projects across many locations, with many trajectories, and from diverse intellectual departure and arrival points (Suchman 2007, P261). The ambiguity of – and possible suspicion towards – the desirability, let alone possibility, of aligning or enforcing intersection of these projects is ANT's strength.

Fourth, qualifying texts as relational warns readers and writers to heed ANT's caveat of stories having provenances and prospects. Emphasis on particularity flags ANT texts claiming *any* overarching objectivity. Law's experience of ANT, as practices lived in and among science and technology studies (STS), whose authors include Bruno Latour, John Law, Donna Haraway, Lucy Suchman, and Arthur Tatnall, recount relentless specificity and restless curiosity.

Ensconcing industrial design research in ANT texts' as a kind of thought-laboratory by may be as simple as characterizing design research as partially defined, perennially multidisciplinary, perpetually interdisciplinary, intransigently trans-disciplinary, permanently post-disciplinary, or practice-situated.[26] These lab-equivalent texts situate theoretical and technical approaches to discovery, creation, or reinterpretation of knowledge. Designing reflexive research material in, and for, ANT settings subverts, resists, and evades overarching theoretical frameworks. Lifting restrictions on materiel serves research design diversity. Reflexive design-practice-grounded readings of industrial design research literature sidestep the construction of a multi-disciplinary theoretical framework. Pursuing data relevant to fluctuating and flowing participants requires correspondingly manifold responsivity to participant's distributed co-collation and analysis.[27]

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[26] Latour, Bruno. A Dialog on Actor Network Theory with a (Somewhat) Socratic Professor. In The Social Study of Information and Communication Study, edited by C. Avgerou, C. Ciborra, and F.F. Land. Oxford University Press. 2004. P69
[27] Ibid. P158

The major writers of relevance to this research offer general theoretical and specific empirical texts. I approach these texts as the “functional equivalent” of the laboratories I have worked in, in my creative, reflexive industrial design practice.[28]

ANT provides for me explanatory ground, and intellectual inspiration for teleparamedicine, wearable computing, and WEHST tool design. The human-based computation processes central to these designs challenges readers and designers to familiarize themselves with some of the concerns underpinning a non-anthropocentric philosophical anthropology.

2.1 The ANT-Approach

The ANT-led approach adopted in this research in the three inter-connected fields of fields of industrial design, wearable computing, and teleparamedicine is predicated on a process-oriented constructivist lens. This exploratory research is congruent with a grounded-theory approach of qualitative investigation, and is appropriate to human-mediated teleparamedicine sites where sufficient quantitative data may be difficult to collect. My exploratory research has adapted to data limitations and short decision-making time frames by combining parallel case studies and field research via participatory approaches over a long time frame. This permits parallel and iterative co-definitions of problems, which suits the deeply reconfigurable WEHST problem space.

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[28] Ibid. P69

Human-mediated teleparamedicine processes oblige engaging reflexive research modes, whereby industrial design practice-led collaborative research tests concepts before finalizing designs. Whether termed cooperative, collaborative, or participatory, stakeholder involvement in practice-led design research is needed for practices, such as teleparamedicine, that are risky. While stakeholder and industrial collaboration presents intellectual property challenges my research project demonstrates how to avoid disclosing sensitive intellectual property during in-depth interviews and focus groups.

The questionability of ANT-and-process-theory-grounded research into human-mediated teleparamedicine means that there is a speculative dimension to this industrial design exercise. Prospective WEHST toolsets employ parallel programming and deploy distributed computing in the field, both of which are ambitious technical aspirations.[xiii]

Finally, this is translational research, making findings from basic science useful for practical applications in teleparamedicine. This translational research connecting knowledge from multiple compartmentalized sciences aims to advance applied science through multidisciplinary bidirectional collaborations “from basic research to patient-oriented research, to population-based research and back.”[29] Translational research is a clear model for the careful WEHST deployment in other teleparamedicine participatory action research programs and participatory design practices. Using systems such as WEHST creates new knowledge into, for, and through multidisciplinary teams working

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[29] Rubio, Doris McGartland; et al. Defining Translational Research: Implications for Training. Academic Medicine: Clinical and Translational Research. March 2010, Volume 85, Issue 3, pp 470-475

towards shared goals through research designs for real-world contexts.[30] Translational research aligns academic researchers with the teleparamedicine stakeholders including manufacturers, operators and regulators. These participants daily confront problems demanding iterative approaches to dynamic interplay of disparate stakeholders.[31] As Bruno Latour describes,

> The first solution [to making an object's activity easily visible] is to study innovations in the artisan's workshop, the engineer's design department, the scientist's laboratory, the marketer's trial panels, the user's home, and the many-socio-technical controversies. In these sites objects live a clearly multiple and complex life through meetings, plans, sketches, regulations, and trials. Here they appear fully mixed with other more traditional social agencies. It is only once in place that they disappear from view. This is why the study of innovations and controversies has been one of the first privileged places where objects can be maintained longer as visible, distributed, accounted mediators before becoming invisible, asocial intermediaries.[32]

As Latour articulates, innovation and controversies are places for reflexively creating new knowledge about design research to understanding the role of mediation and intermediation. Pursuing practice-oriented ends by practice-led means are processes of digging into controversies. Teleparamedicine is an explicitly complex and processual problem, and WEHST is a distributed and decentralized solution.[xiv]

2.2 From the Black Box to WEHST

Latour translated the term "black box" from engineering vernacular into a central tenet of sociology of science and science studies. Similarly, I develop black boxes as both conceptual associations of teleparamedicine actors and as technical blueprints for

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[30] Ibid.
[31] Ibid.
[32] Latour, Bruno. Reassembling the social: an introduction to Actor-network theory, Oxford ; New York, Oxford: University Press, 2005. P79.

WEHST's concrete modules. Teleparamedicine systems can be as single or multiple black boxes. WEHST is assembled from constituent submodules by material and semiotic opening and closing at multiple scales. Counterpoising the openness and closedness of WEHST leads to module-and-system-level trustworthiness and indefatigable self-interrogation.

Latour is my "obligatory passage point" (OPP) for ANT literature's exploration of "collective sociotechnical processes,"[33] His accounts of scientific knowledge production align with ANT's ethno-methodological origins. Latour's ideas are the most readily mobilized in the context that I have outlined in this thesis.

Applying ANT to describe human and non-human actants in teleparamedicine and WEHST design practice requires relentless specificity to create compelling fictions. ANT supports detailed accounts of actants' mechanisms of association and re-association among irreducibly heterogeneous realities that correspond with plural sources of agency. ANT's (and Latour's) philosophical indeterminacy indicate ANT "is clearly work in progress"[34]   Contemporary ANT texts are mediators conveying thick descriptions of the actor network being studied. Latour characterizes ANT case studies as more objective, lively, and empirical than the clichéd explanations of positivist approaches to objectivity,[35] However, ANT descriptions are incomplete and, as Finn Collin highlights, Latour characterizes his case studies as "fictions," because the phenomena investigated are always partial accounts emphasizing particular features of detailed pictures unembellished by explanatory frameworks. Any description highlights

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[33] Ritzer,George. Encyclopedia of Social Theory. SAGE Publications, 2004. Page 1
[34] Collin, *op cit*. Science Studies as Naturalized Philosophy. 2010. P137
[35] Latour, *op cit*. Reassembling the social 2005. P157

certain features and hides others. With the explanatory ambition gone, no particular description forces itself upon us; the question is only which features we want to highlight in the phenomenon in question. [36]

As John Law writes, actor-network-theory is an approach to sociotechnical analysis that treats entities and materialities as enacted and relational effects, and explores the configuration and reconfiguration of those relations. Its relationality means that major ontological categories (for instance 'technology' and 'society', or 'human' and 'non-human') are treated as effects or outcomes, rather than as explanatory resources.

> Actor-network theory is widely used as a toolkit in sociotechnical analysis, though it might be better considered as a sensibility to materiality, relationality, and process. Whether it is a theory is doubtful.[37]

John Law's pitch of ANT as a material-semiotic and relational means for description and "a toolkit in sociotechnical analysis"[38] is consistent with my own project-led research findings. Latour, ruminating on the role of the text calls attention to the act of writing within ANT:

> Because this text, depending on the way it's written, will or will not capture the actor network you wish to study. The text, in our discipline, is not a story, not a nice story, it's the functional equivalent of a laboratory. It's a place of trials and experiments. Depending on what happens in it, there is or there is not an actor—and there is or there is not a network being traced. And that depends entirely on the precise ways in which it is written. Most texts are just plain dead.[39]

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[36] Collin, Finn. Science Studies as Naturalized Philosophy. Springer Science & Business Media, 2010. P125

[37] Law, John. After Method: Mess in Social Science Research. Routledge, 2004. P157

[38] Law, John. Actor Network Theory and Material Semiotics. John Law, 'Actor Network Theory and Material Semiotics,' version of 25th April 2007. downloaded on May 18, 2014 from http://www.heterogeneities.net/publications/Law2007ANTandMaterialSemiotics.pdf.

[39] Latour*, op.cit.* A Dialog on Actor Network Theory with a (Somewhat) Socratic Professor. 2004. P69

Assembling the texts of Bruno Latour, John Law, Donna Haraway[xv], Lucy Suchman[xvi], and (editor) Arthur Tatnall IJANTTI[xvii] into this Ph.D. thesis furnishes laboratories and experimental populations of radically indeterminate actors.[40] [xviii] How these authors position actors within their case studies offers instructive benchmarks. Where texts have succeeded (in my reading of them) indicates where some future cross platform successes of technology may arise. While I read ANT as an unfolding of collective processes rather than a strict method, ANT suggests that there are three general principles that are fundamental to the description of networks and relations: agnosticism, symmetry, and free association.

"Agnosticism" is the divestment of *a priori* assumptions about network provenance or veracity of actants' self-portrayals[41] including impartiality towards not predefining who may be actors or what is their part in action. "Generalized symmetry" is interpreting all actants through the same benchmarks. "Free-association" divests actants of natural versus social distinctions. These categories are not causes but effects. These three principles – not rules – safeguard ANT's own understanding of itself as "not a theory." While theory abstracts, ANT does not. ANT descriptions do not explain anything, as Callon claims.[42] ANT accounts are not contextual generalizations based on analytical viewing of particular and empirical phenomena.

Critiques of ANT are rooted inside of its very tradition. Latour famously challenges everything about "actor-network theory" including the hyphen. Despite

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[40] Ibid.
[41] Callon , Michel. Actor-network theory - the market test. Chapter ten of Actor Network Theory and After. edited by John Law and John Hassard. Oxford ; Malden, MA : Blackwell, 1999. P182
[42] Ibid.

permitting relational analyses, John Law raises objections to actor networks, which[43] given increasing ubiquity of the network metaphor[44] in public, private and academic spheres, validates the question: "Have actor-network theorists unintentionally replicated a hegemonic version of reality?"[45] Latour bemoans the lack of translation in popularized conceptions of networks. However, many contemporary technological networks demonstrably track and transform all intentional and inadvertent participants. Public literacy of (and lucid participation in) technological networks is approaching some congruency with ANT negative argument cum philosophy.

Evaluating the tenor of ANT's vaunted non-detachment raises questions of Latour's responsibility for the path ANT takes. For example, Steve Matthewman asks, "Was [Latour] merely describing a world or helping to legitimate one?"[46] Matthewman's concern for researcher co-option through network hegemony and researchers' performance of networks is combined with a vague fear of Latour's "functionalist version of networks and relationality," which Matthewman claims make researchers managerialist.[47] Overall critiques of ANT identify its neglect of those "structural determinants" supporting and sustaining networks.

It is my belief that one might ameliorate these concerns through the iterative refinement of research-design processes entailed in the industrial design of human-based and situated computation material. ANT arose through un-black boxing – through

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[43] Latour, Bruno. On recalling ANT. Chapter two of Actor Network Theory and After. Edited by John Law and John Hassard. Oxford; Malden, MA : Blackwell, 1999. P15-25; Callon*, op. cit.* Actor-network theory - the market test. 1999. P182
[44] Knox, Hannah and Savage, Harvey. Social Networks and the Study of Relations: Networks as Method, Metaphor and Form. Economy and Society. Volume 35, Issue 1, 2006. Pages 113-140
[45] Latour*, op. cit.* On recalling ANT. 1999.
[46] Matthewman, Steve. Technology and Social Theory. Palgrave Macmillan. 2011. P123
[47] ibid

field studies that described, unpacked, and analyzed – actual research laboratories. One's research material adapts in the field, *becoming* in real-time. ANT perspectives are commensurate with rigorous ethnographic knowledge production by refusing to black-box humans or their habitats. The increasing scope of ANT-grounded definitions of technology may interpolate the ecological and anthropological in human-based computation.

ANT approaches make relationships amid heterogeneous networks describable without unilaterally resorting to the bricolage of closely specified technical jargon. This may aid disparate actors to leverage various states of embodiment to communicate and cooperate.[xix] ANT proffers black-boxing as a process for stabilizing relationships among teleparamedicine actants. ANT designation of designed objects as becoming actors underscores my resolution to address teleparamedicine design as a 'wicked' problem of giving WEHST partial autonomy. Such self-sufficiency arises through distributing control to, while decentralizing control at, levels of both individual modules and as whole-body networks of multiple modules.

My design project pursues WEHST as a practical means of maintaining semi-autonomous technology's equilibrium with telehealth teams which include active participation by designers, researchers, and teachers. ANT-grounded adaptive system architecture does not automatically institute conditions for WEHST volitional self-design innovation, but allows actors including teams of paramedics, multi-agent systems of wearable computing, and telemedical ecosystems themselves to autonomously continue composing and creating their own innovations through association.

Shifting up and down the registers of possible characterizations and untold combinations of teleparamedicine black boxes brought me first to human-mediated teleparamedicine practice system, then to the WEHST product system of a family of eight sub-families, and finally to the COMmand sub-family of devices. Anecdotal threads running through all my field studies converged to describe a basic unmet need connecting all study participants. Coparticipants' shared need positioned particular inputs and outputs designating a black box on their bodies, among teams, networked technologies, and in their webbed environments. This black box first designated an intermediary whose internal complexity remained contingent on unspecified system-level designs of a modular, scalable, and adaptive architecture. Through design this black box was unpacked and then re-black boxed to become a mediator. Verifying and refining this design required succeeding field studies to reproduce the initial findings.

Anecdotally, in the field my study participants' radio communications break down half of the time. Too much goes wrong. Radios conventionally involve mobility on bodies and vehicles partly intersecting with fixed telecommunications infrastructure; manual or speech control of radio settings; listening to and conveying the sound of paramedics' voices; visual and auditory status display; and detecting, translating, and transmitting voice, button-press, or multimedia signals. Successful radio communications comprise a big black box of radio, bodily, and environmental co-performance.

In high-risk, time-sensitive situations wearable devices (grounded in contemporary technologies capabilities) must buffer their own capabilities and adapt to situational challenges by enrolling human embodied sensory and cognitive competencies. Problems of voice-activated, speech-recognition, or manual press-to-talk radio communication include poor speech clarity, loss of control, slow speed of delivery, and ambiguous voice identification. Buffeting by environments, suffocated by personal protective equipment, and perturbed by fluctuating bodily states periodically destabilize black-boxed radio operators. This is evidenced by operator stories of intermittent radio breakdowns overcome by shouting, physical touch, lip-reading, hand signals, manual rope pulls, flag semaphore, signal lights and chemical flares. ANT enables black-boxing processes crossing boundaries of existing products, people, and environments. This black-boxing proposes general solutions to complex system-of-systems problems. Paramedics need their radios to perform predictably. I want to stabilize radios worn on paramedic's bodies in disruptive environments. Depunctualizing actor networks or physically opening the radio expends social, political, material, economic, and ecological resources of multiple paramedics and designers'.

2.3 ANT role in how "object" is designed

The WEHST object comprises an association among interoperable heterogeneous modules. ANT's role in how it is designed commences with including ANT literature in data collection and analysis processes. ANT's vocabulary is appropriately flexible to describe how, who, what, where, and when, yet without presuming to explain why, mediators are constituted, distributed, and translated among teleparamedicine's processes.

ANT's concept of translation enables designing for continuous transpositions, rearrangements, displacements, and disarticulations of non-local and non-unitary relationships endemic to telepresence. ANT offers formal yet permissive means of identifying and concurrently designing for the full range of teleparamedicine stakeholders. ANT's agnosticism, generalized symmetry, and free-association garner informants' descriptions to proffer as evidence guiding design for telehealth processes of care at a distance. ANT acknowledgement of designed objects as actors (see Appendix 10.1 for discussion of ANT-type actorship in teleparamedicine) underscores my resolution of the wicked problem of human-mediated teleparamedicine design by giving WEHST partial autonomy at levels of both individual modules and as whole-body networks of multiple modules.

ANT contributes to human-mediated teleparamedicine design through sociotechnical analyses processes suitable for investigating, and translation into research materiel constituting explicit physical analogs of associations traced among ANT actors. Reciprocally, the whole of human-mediated teleparamedicine design contributes to ANT through its promise as research materiel suitable for investigating, and becoming explicit physical analogs of, processes and theories for tracing associations of actors. ANT's role in how the "object" is designed is in questioning "through which procedures is it possible to reassemble the social not in a society but in a collective?"[48]

2.4: ANT and WEHST: the example of the COMmand module

ANT's role in how human-mediated teleparamedicine experiences, WEHST systems, and discrete WEHST modules (such as the COMmand device) are designed

[48] Latour*, op. cit.* Reassembling the Social. 2005. P16

is as a socio-technical analysis tool writ both small and large. In the following description of how ANT contributes to WEHST design I use the COMmand module to stand in here for the greater WEHST product system. COMmand gives a narrower, still concrete, design instance to inscribe ANT conformations upon. Just as ANT is a thing for describing things, the subsidiary COMmand module is a tool helping (the literature review) describe ANT, and is not what is being described.

COMmand works to intermediate convergence of bodily psychophysiological, social (human), technical, and environmental networks in order to translate paramedic objectives into control of their radio. Symmetrically, COMmand translates radio (and remote actors) objectives to achieve the same goal of aligning operator and radio by increasing the degree, range, and rate of feedback circulation. Control of radios is degraded by ambient sound interference, when speech is impaired, and when paramedics cannot manually switch their radios.[xx]

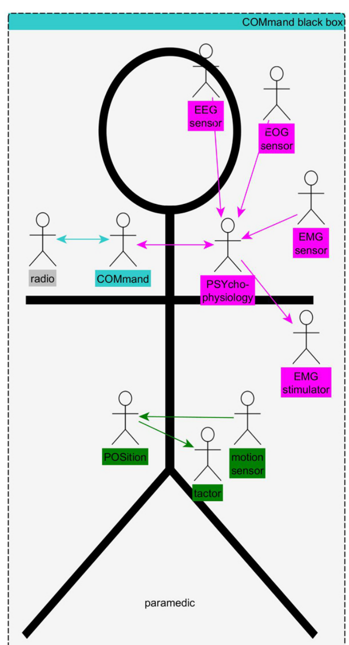

Figure 2.1 COMmand black boxes the body, itself, associated WEHST components, and radio.

Hands-and-voices-free control hybridized with remote control of body-worn radios is proposed to practically reduce paramedic's physiological and cognitive load while operating radios and telepresence equipment. The ANT role in designing WEHST "objects" is to allow me to describe what I nominally entitle the narrowest instance of black boxing this paramedic embodiment based control of technology: a *wearable multimodal synesthetic feedback control interface for hands-free/speech-free/voice-free radio operation*. This title also describes the COMmand black box as a discreet module connecting a variety of radios by recombining smaller subsystems of sensors and emitters from the larger WEHST tool box as an interface working for two-way operator-to-radio control-feedback.[xxi] Non-verbal, non-manual, bodily-control of body-worn radios does not require changing a radio's core architecture. Improving basic radio function and extending its capabilities are possible with a separate module coordinating nominally standardized paramedic, radio, personal protective equipment, and specialists amid multiple environments. The device's modular and multimodal configuration requires real-time, user-defined blending of voluntary and involuntary signals to control the radio. Signals correspond to psychophysiological, gestural, speech, technical, and environmental phenomena. Coupling multiple modes of feedback warrant signals are sent and received accurately.[xxii]

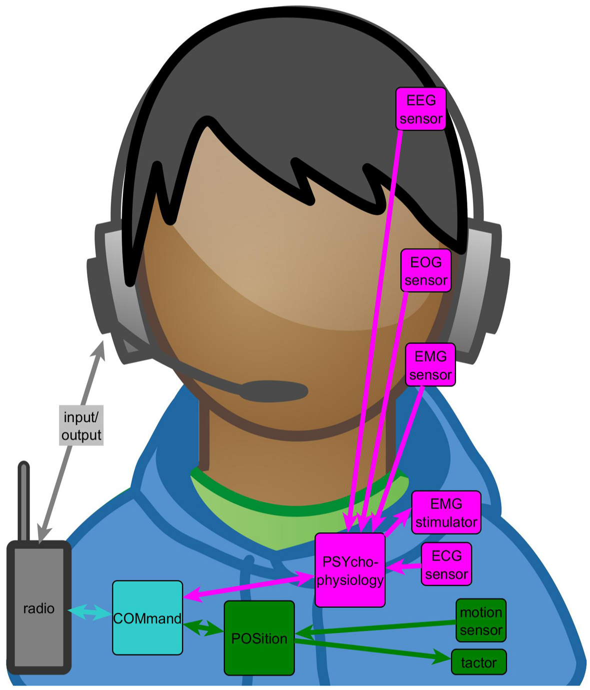

Figure 2.2 The COMmand montage may vary in peripheral type, size, position, and number.

Immediate uses of an original way of hands-and-voice/speech-free operation of commercial radios are as a self-reconfiguring modular actant. Its value is in achieving different network morphologies of body, radio, environment, and itself, and coupling these with systems for distributing control within widening networks. For example, COMmand-enabled hands-and-voice-free actuating and adjusting radio channels and controls in high-risk settings needs to periodically remain firmly "closed" (black boxed). Closedness requires close human companionship of skilled operators, who buffer the vagaries of messy, painful contexts.

> The more automatic and the blacker the box is, the more it has to be accompanied by people. In many situations, as we all know too well, the black box stops pitifully because there is no salesperson, no repairer, no spare part. Every reader who has lived in an underdeveloped country or used a newly developed machine will know how to evaluate the hitherto unknown number of people necessary to make the simplest device work! So, in the most favorable cases, even when it is a routine piece of equipment, the black box

requires an active customer and needs to be accompanied by other people if it is to be maintained in existence. By itself it has no *inertia.*[49]

Receding into background intermediacy is among COMmand stabilization strategies supporting intervention in brief high-value interludes of hands-voice-free toggling between manual, voice-activated, and speech-recognition control of radios.

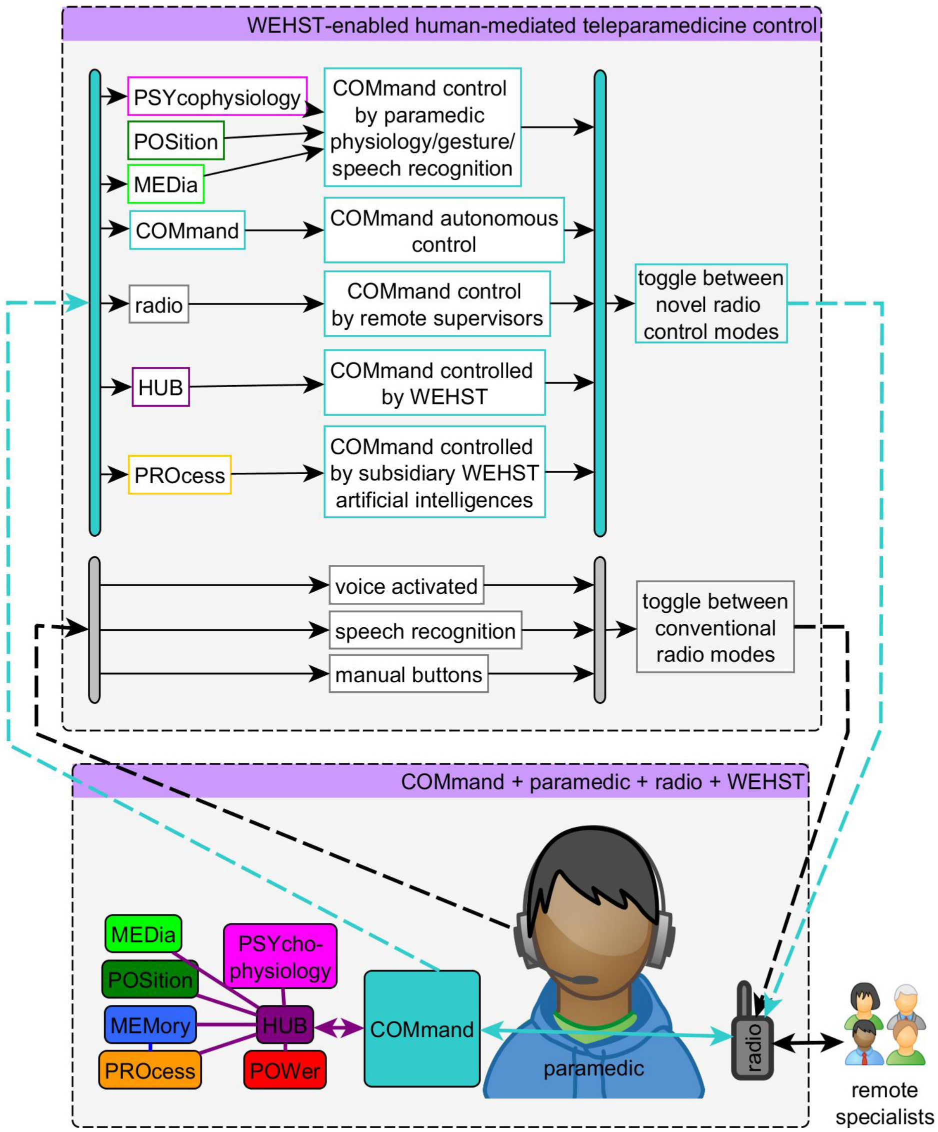

Figure 2.3 COMmand black boxes multiple modes of WEHST enabled input and output for a paramedic for hands-free-free/voice-free radio operation. COMmand also offers real time control of a wide spectrum of telepresence media devices other than a radio.

[49] Latour, Bruno. Science in Action: How to Follow Scientists and Engineers Through Society. Open University Press: Milton Keynes; 1987. P137

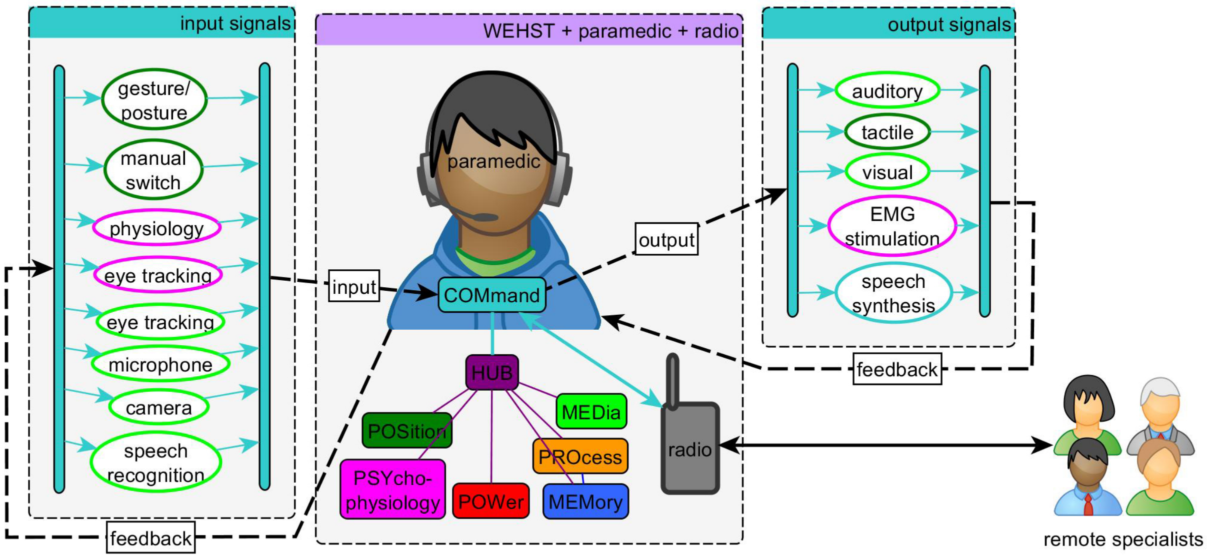

Figure 2.4: Thousands of possible combinations of WEHST subsystems (COMmand, PSYchophysiology, POSition, and MEDia) can be black boxed by COMmand in conjunction with particular (and changing) anatomical sites and physiological processes to control their radio. This offers an instance of *Multimodal Synesthetic Feedback Control Interface for Hands-Free-Free/Voice-Free Radio Operation.*

The role of COMmand is to circulate control loci among itself, WEHST, paramedics, paramedics' body-worn radios, and remote supervisors. COMmand apportions co-control to itself, its WEHST montage, paramedic, radio, remote supervisors, and environment. COMmand is a focal ANT actor designate. This focal actor inscribes network's interests into paramedic's bodies. Simultaneously, its wearers inscribe their own psychophysiological safeties into teleparamedicine networks via COMmand modules. COMmand is a proxy focal actor keeping paramedics anchored in teleparamedicine network translation and inscription processes. Such mooring is crucial when paramedics' cognitive and physical loads jeopardize teleparamedicine network alignment or cohesion.

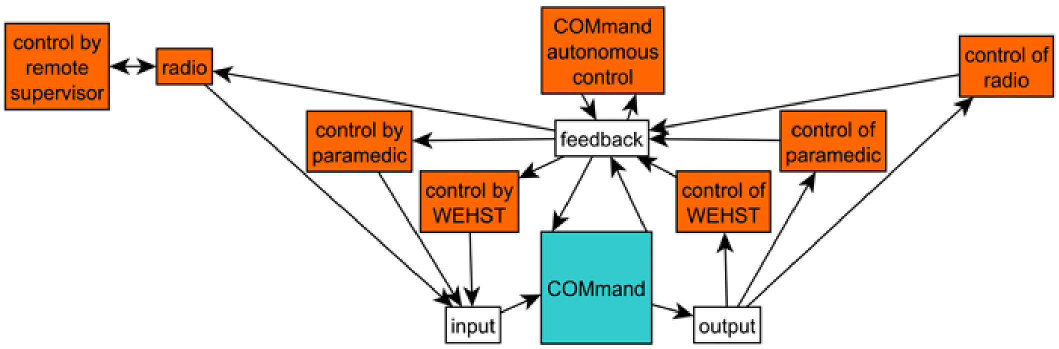

Figure 2.5 Various human-mediated teleparamedicine control architectures may be black boxed as COMmand input/output/feedback configurations.

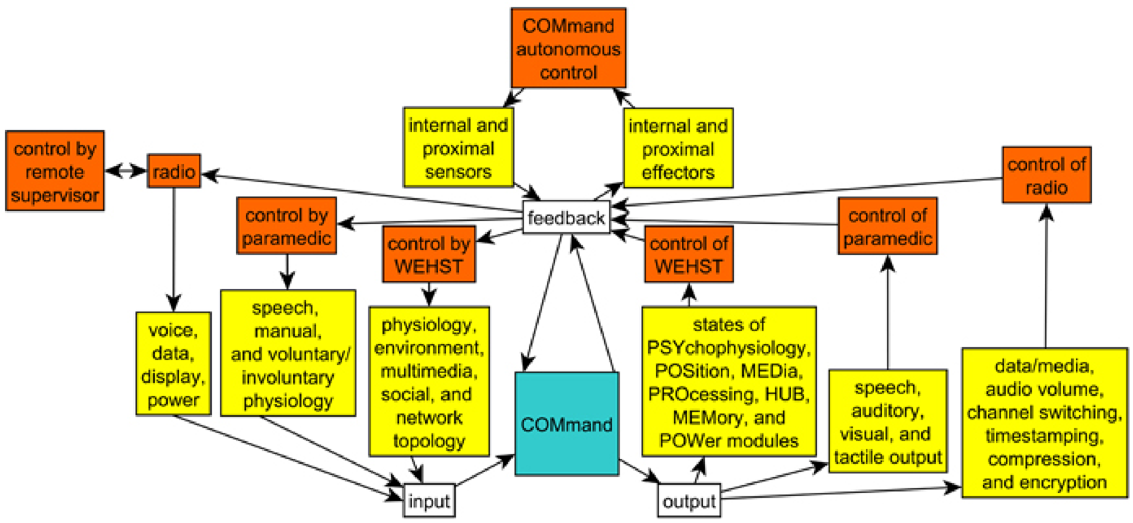

Figure 2.6 Detailed view of signals types black boxed as COMmand input/output/feedback.

The COMmand device innovation is in giving technology developers and researchers, teachers, and practitioners a tool performing manual (by paramedic wearers), autonomous, or remote switching between intermediary and mediator modes. COMmand alternately opens and closes black boxes of itself (itselves) and of paramedics'. The COMmand black box coordinates decentralized circulation of co-control loci between body and devices. This surmounts difficulties of stabilizing and scaling up a product useful in unpredictable environments of combined physical exertion, high noise and vibration levels, and human and radio sensory overload and mechanical breakdown. The COMmand black box excludes these contextual actors by tying paramedic to radio to team in order to resist perturbations outside this black box. One among many other teleparamedicine network actants, the COMmand module defines and controls itself, its wider WEHST montage, its human-in-the-loop, on-the-body radios, its relationships across distinct teleparamedicine sites and teams, associated personal protective equipment, and portable medical instruments.

The goal of black-boxing a paramedic with their remote teammates, by having a body-worn black box continuously re-tie connections between paramedic and radio, is to buffer processes of competing networks continuously untying paramedic-radio connections. The COMmand black box is an actor-network and a design for tools stabilizing its own, its wearers', and its extensive entourage of teleparamedicine actants performance. It does so by continuously redefining its operators' relationship with subsidiary teleparamedicine actors.

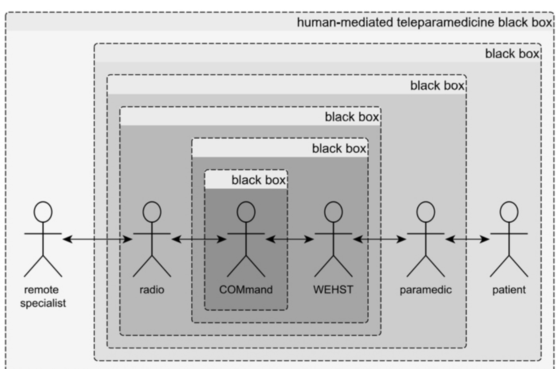

Figure 2.7 COMmand black boxes at multiple scales to support human-mediated teleparamedicine.

The COMmand black box situates configuration of sensor-emitter feedback processes translating paramedic's voluntary and involuntary bodily, telecommunication, and environmental signals into real time control of mobile radios.

The COMmand black box integrates whole sets of subsidiary black boxes by enabling their input and output to stabilize periodically. As this modular device always becoming part of the paramedic, it suits accident investigation, analyzing safety issues, detecting equipment degradation, and measuring human performance. A COMmand module focuses on turn-taking between itself, its operator, the radio, and remote supervisors or computational resources. COMmand is not too tightly coupled with other components of a paramedic's entourage of matériel. Loosely and intermittently coupled with non-radio or non-operator actors, such as local environments or remote supervisors, COMmand synthesizes and improvises communication with intermittent co-actors. Such ad hoc communication adheres to the human bodies' standard interface, which include microclimates, physiology, ergonomics, anthropometrics, and accoutrements.

COMmand is a prescriptive placeholder demonstrating ANT's value in system-level industrial design. While the individual modules constituting WEHST are distilled into discrete units (such as COMmand, POSition, HUB, etc.) each unit is in fact an aggregate arising from an internal multi-processor architecture system echoing the complexity of preceding findings regarding WEHST and teleparamedicine systems. In the following diagrams I describe the internal multi-processor architecture system while allowing the individual processors to remain black boxed.

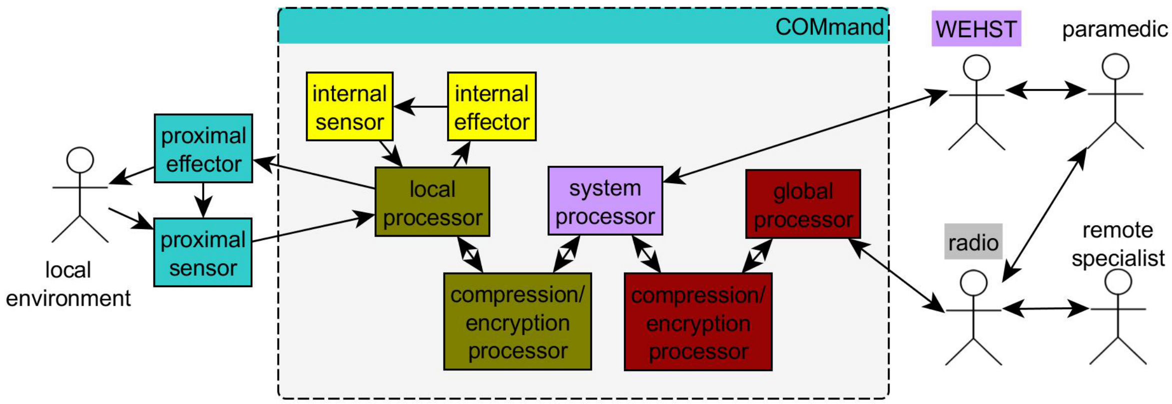

Figure 2.8: Inside the black box of the COMmand module an internal architecture of multiple processors grants multiple scales of feedback-based control.

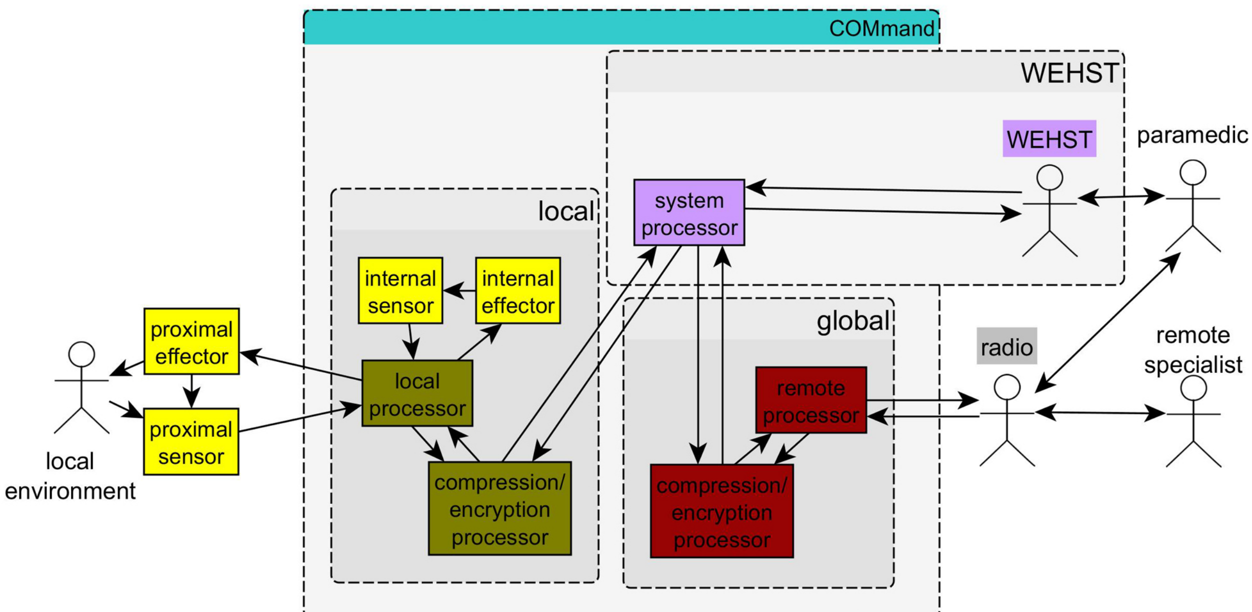

Figure2.9: Three scales of black boxing control local to the COMmand module, of the WEHST system, and of remote communication with other sites.

ANT's central concept of translation applies at all levels of teleparamedicine from paramedics bodies to individual processors. Translation suitably describes many adaptations by WEHST's intra-module processor architecture and WEHST's inter-module architecture. COMmand's processor architecture sustains WEHST's adaptations by translating successive environmental variations into growth and development of teleparamedicine actants and processes. For example, COMmand quickens paramedic operator response time and expands communicative competencies to ensure plasticity of teleparamedicine self-organizing systems processes. My project takes COMmand as an actor translating teleparamedicine actors-in-dispute into action at a distance. COMmand is an innovative translation tool not fully adoptable, never carried out in full, and always usable differently than expected.[50] The COMmand module in a teleparamedicine network supports human actors in all four "moments" of problem translation: Problematization, interessement, enrollment, and mobilization.[51]

Problematisation[52] is the "how to become indispensable" instant of constructing the problem of collecting COMmand traits into a product for cohering wider teleparamedicine processes. The COMmand is first composed as a project of designing an 'obligatory passage point' (OPP) relationship for teleparamedicine. Second, COMmand comprises an iterative teleparamedicine project for which COMmand is the focal technical actor in the project of achieving robust and stable human-mediated teleparamedicine actants. COMmand problematizes a teleparamedicine network in terms of complements of indispensable actors including paramedics, wearable communications and computation, personal protective equipment, remote specialists, and telemedical environments. These compositions are orchestrated through COMmand fulfilling its obligatory passage point role. COMmand adapts on-the-fly by allocating telecommunication resources. This coordination includes transitions between

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[50] Iyamu, Tiko and Tatnall, Arthur. The Impact of Network of Actors on the Information Technology. Chapter 16 of Actor-Network Theory and Technology Innovation: Advancements and New Concepts. IGI Global, 2011. 2011. P234

[51] Callon, Michel. Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. First published in J. Law, Power, action and belief: a new sociology of knowledge? London, Routledge, 1986, pp.196-223

[52] Puripat, Charnkit, and Tatnall, Arthur. Knowledge Conversion Processes in Thai Public Organizations Seen as an Innovation: The Re-Analysis of a TAM Study Using Innovation Translation. *Social and Professional Applications of Actor-Network Theory for Technology Development.* IGI Global, 2013. 88-102. P97

real-time (synchronous) and store-and-forward (asynchronous) modes; connecting nodes with heterogeneous latencies, bandwidths, and coverage zones; and technical, jurisdictional, and disciplinary coordination.

In problematization COMmand lobbies teleparamedicine actant networks to be designated an indispensable focal actor, both in finding problems and by offering solutions in an exaptation[xxiii] process of shifting roles of actors recruited by COMmand. For example, a temperature sensor used by COMmand to track paramedic body temperature may have COMmand renegotiate its role to instead monitor for damage to paramedic personal protective equipment. COMmand-embodied obligatory passage point processes include developing degrees of power, precision, speed, and range for teleparamedicine cohort-level adaptations to wider changes. COMmand, as human-based computation obligatory passage point of teleparamedicine cohort-level adaptation, defines and enumerates who, where, and what the network is.

Interessement is described by Callon[53] as "how allies are locked into place" instants of recruiting groups of actors into accommodating rules defined for them by the wider network. COMmand is designated both intermediary and mediator as it is occasionally autonomous, but more often aligned with other groups. Interessement processes occur at multiple scales and degrees of synchronicity. The macro scale of teleparamedicine network interessement matches field tasks to network resources by shifting the control locus (or hybrid control among loci) among local paramedic, semi-autonomous COMmand, or remote specialists and administrators. At meso scale

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[53] Callon, *op. cit.* Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. 1986.196-223

interessement streamlines and optimizes the paramedic-COMmand-radio control-feedback loop via pruning and tuning voluntary and involuntary body signals sensor-effector modes and syntax. This allocates bodily, technical, economic, and environmental resources toward robust human-based computation. At the micro scale COMmand coordinates its internal processors, its host of psychophysiological and environmental sensor-effector peripherals and submodules, and the radio. Micro-scale intra-COMmand associations stabilize the macro-scale team, and meso-scale of paramedic plus radio, by configuring and synchronizing system settings and verifying monitoring sites.

Interessement is also the moment where teleparamedicine actants define their degrees of flexibility. Out-of-the-box COMmand's modular architecture is too flexible for most teleparamedicine contexts. COMmands' hardware, firmware, middleware, software, operating system, operator, first-response team, union, employer, regulator, distributer, and manufacturer need to be iteratively configured in use. Configuration occurs along this gamut to maintain peak performance and safety in heterogeneous teleparamedicine networks. COMmand also stabilizes teleparamedicine network equilibrium of specialists versus generalists at points corresponding to: macro situations of multidisciplinary trades and teams; infrastructure and matériel; budgets and economies; size, duration, and extremes of environments. Meso-scale sizing and grading for individual ergonomic, biomechanical, and anthropometric characteristics includes accommodating variations in individual paramedic skill, experience, and learning ability. Loose or tight paramedic-to-COMmand coupling determines levels of specialization of paramedic-to-COMmand syntax. Competent embodied communication gives increasing range of vocabulary and rates of speech and metacommunication.

COMmand reflexive interessement sets its own role in terms of flexibility to adapt. It adapts to electromechanical failures such as physical damage or radio-frequency interference, and degradations of telecommunication latency, bandwidth, and sensing fidelity. COMmand does this internal to itself, radio, WEHST montage, and paramedic body by varying sensor modes, effector combinations, redundancy, and multimodality; power management; signal processing; interoperability; networking; and encryption. COMmand organizes the teleparamedicine network to renew consensus regarding how the obligatory passage point adjusts the teleparamedicine network to changes within situations, anticipating changes between settings, and adapting to unforeseen circumstances.

Enrollment is the "how to define and coordinate the roles" instant[54] of network acceptance processes beginning. This acclimatization comprises mostly automatic physiological, technological, and environmental adjustments occurring during operation in new configurations and changing situations. As seduction, consent, or coercion, enrollment is adoption-in-process among multiple actors taking, holding, and yielding ground in the emerging actor network. [55] This moment amalgamates local, remote, and autonomous control of multiple modes of feedback to ensure signals are sent and received accurately and quickly. For example, COMmand enrollment defines and extends the equilibrium of voluntary and involuntary psychophysiological, gestural,

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[54] Iyamu and Tatnall, *op. cit.* The Impact of Network of Actors on the Information Technology. 2011. P237
[55] Uden, Lorna and Francis, Janet. Actor-Network Theory for Service Innovation. International Journal of Actor-Network Theory and Technological Innovation (IJANTTI), Volume 1, Issue 1, 2009. P28

postural, tactile, visual, and auditory signals. This equilibrium becomes more specific as the actor network grows. COMmand internal signaling networks coordinate the teleparamedicine actor network to conserve limited resources during periods of scarcity of cognition, computation, power, labour, money, time, media, blood sugar, hydration, oxygenation, blood pressure, heart rate, and medications. Enrollment processes establish a stable network by multilateral feedback processes adjusting their alliances to match expectations with actual and changing conditions.

Mobilization is the "are the spokespersons representative"[56] instant of wider acceptance of newly stabilizing teleparamedicine networks. COMmand's positions within local, remote, autonomous, or hybrid control architectures of actor networks are as either a focal actor or as their spokesperson. While only occasionally a focal actor, COMmand is more often "secondary focal actor"[57] arising as newly situated spokespersons are now oriented on project targets set by focal actor.[58] COMmand, performing analogously to a wearable router, enables a more expansive network of absent actors to emerge through spokespersons promoting network adoption. A goal of spokesperson-mobilized learning may be to improve paramedic performance on long or short baselines. For example, COMmand creates and links sub-networks of collections of actors, and as a collective.[59] Linkages create associations and accelerate and reinforce learning. Spokespersons' capacities to learn and teach arise from experiences

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[56] Charnkit and Tatnall, *op. cit*. Knowledge Conversion Processes in Thai Public Organizations Seen as an Innovation. 2013. P97

[57] Iyamu, Tiko. Institutionalisation of the Enterprise Architecture: The Actor-Network Perspective. *IJANTTI* Volume 3, Issue 1. 2011 pp27-38.

[58] Iyamu and Tatnall, *op. cit.* The Impact of Network of Actors on the Information Technology. 2011. P239

[59] Linden and Saunders, *op. cit.* Linux Kernel Developers Embracing Authors Embracing Licenses. 2009. P150

in particular actor networks. Their multilateral co-constitution as focal actor, spokespersons and wider networks of absent entities mobilize multiple processes of self-study at parallel scales. Thus, COMmand constitutes quantitative and qualitative research matériel nominally reinforcing a robust control-feedback loop. This reduces false positives and hastens error detection and correction. This learning by actor network adaptation is a widely distributed teleonomic[xxiv] process of learning by paramedic, COMmand, and WEHST becoming commonplace in the field as representatives are verified by ongoing acceptance.[60]

> By localizing the circulation, production, formatting, and metrology of the social inside tiny, expansive, and expensive conduits, we have already opened a space in which other types of entities may begin to circulate.[61]

In conclusion, the ANT approach is important for it provides a way to understand how the teleparamedicine "object" is designed. Designating multiplicities as the stabilizing foundation of teleparamedicine processes fits how "in theory the body may be single but in practice it is multiple because there are many body practices and therefore many bodies."[62] This assumption of multiplicity sidesteps early critiques of ANT by dispelling the goal of a "single co-ordinated network and a single coherent reality."[63] What ANT offers are a means to guide the design of WEHST to be prepared to address the question of "how to *deploy* the many controversies about associations without restricting in advance the social to a specific domain?"[64]

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[60] Underwood, Jim and Edin Tabak. Making Information Systems Material through Blackboxing: Allies, Translation and Due Process. *IJANTTI* Volume 3, Issue 1. 2011. P135
[61] Latour, *op cit,* Reassembling the Social. 2005. P233
[62] Ibid.
[63] Law*, op. cit.* Actor Network Theory and Material Semiotics. P13
[64] Latour*, op. cit.* Reassembling the Social. 2005. P16

Chapter Three: Field Research

> Ethnography is a research approach that can uncover the most intimate details of a life. It therefore demands great responsibility on the part of a researcher, who must be aware of how ethnographic accounts may instigate the opportunity for the abuse intentionally or not of personal experiences.[65]

When using an ethnographic approach, especially with vulnerable groups, it is important to adopt a reflexive stance, a self-questioning at every turn. As Crozier *et al* argue it is important to ensure that,"“… the reflexive approach locates the self within the same as well as different contexts of the research, that it takes into account structural issues and that it interrogates the power dynamics and wider as well as personal influences upon these.”[66]

This chapter discusses what I learned from field observation within those bodies of literatures constituting “the functional equivalent of a laboratory”, among paramedics across multiple design field ethnography sites, in professional design research practice, and in my own industrial design studio.[67] My field research was situated in a web of relationships that demanded a commitment to process. Observations were concurrently described through field notes and visual ethnography. These observations included production of detailed notes, drawings, and diagrams particular to each site and combine interview transcripts, reflections on field-notes, and graphical treatments of scenarios developed through field research.

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[65] Crozier, Gill. Is Ethnography Just Another Form of Surveillance? Methodological Issues and Practices in Ethnography. Studies in Educational Ethnography, Troman, Geoff; Jeffrey, Bob; Walford, Geoffrey (Editors). Volume 11. Elsevier, Inc. San Diego, California. 2005. P101
[66] Crozier*, op. cit.* Is Ethnography Just Another Form of Surveillance? 2005. P107
[67] Latour, op. cit. 2004. P69

3.1 "Literature" Research

> Assembled around the 'laboratory' of the text, authors as well as readers may begin to render visible the two mechanisms that account for the plurality of associations to be taken into account and for the stabilization or unification of the world they wish to live in. On the one hand, it is just a text made up of reams of paper sullied by an inkjet or burnt by a laser beam. On the other, it is a precious little institution to represent, or more exactly to re-represent—that is, to present again—the social to all its participants, to perform it, to give it a form.[68]

Literatures are actors among research and design practice grounded as embodied and situated processes. Literatures integrate multiple sites, happen in those sites, and situate the aggregation of multiple subjective perspectives and the creation of alterior, non-unitary subjectivities. Designing a literary praxis of design research and research design requires attention to presenting readers as active participants in the construction of the ground for the knowledge transmitted. Literatures are active – as nominal actors – participants in their co-construction.[xxv]

Approaching literature as settings containing data[xxvi] for interpretation was through the active seeking of an evolutionary taxonomy fitting general design processes and appropriate for imbuing specific human-based computation designs with evolutionary capabilities exceeding mere adaptations. Constructing an industrial design trope of evolving and ecology-situated human-based computation is a means to translate cultural and environmental signals into technological signaling.[xxvii] I approached the literature of evolution as a means of guiding design of human-based computation processes, products, and policies, towards the ends of creating an ecologically congruent technical and scientific system of teleparamedicine.

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[68] Latour, op. cit. Reassembling the Social. 2005. P139

Donna Haraway's and Lynn Margulis' oeuvres complementarity influences my research more than any other literary sources. Haraway has facility in the discourses of hard sciences and humanities. Margulis has facility in writing hard science in ways ranging from rigorously scholarly to humanized and publicly accessible. Both authors share commitments to the political and philosophical consequences of their research practices.[xxviii] Both authors have developed unique perspectives on the responsibilities of researchers to endeavor to reshape relationships between culture and 'technoscience' and the science of biological cultures to be attentive processes of cooperation and co-constitution.

I read Donna Haraway's work on 'companion species' to understand how to describe actants knotted from human beings, animals and other organisms, landscapes, and technologies. She reveals how humans and 'companion animals' relationships are not human-centered, and her findings translate into understanding human-based computation as a fabric of tightly entangled actors much more diverse than simply humans and anthropocentric computers.[xxix] Haraway's thinking on companion species complements Lynn Margulis' writing on the implications of non-anthropocentric conceptualizations of evolution for understanding symbiotic, concretely cooperative relationships among species and within ecosystems.

Haraway and Margulis' respective authorships reflect, and arise from, profound commitments to interdisciplinarity as both a principle of openness to forming new associations and necessity of overcoming disciplinary biases. To their respective fields' tangled ontologies and philosophically charged concepts of actorship, Haraway and Margulis bring descriptions of biological and ecological phenomenon which challenge reductive models for human experiences. Haraway and Margulis' common preoccupations with symbiogenesis and "companion species" are relevant to process theory grounded human-based computation design.[xxx] Haraway and Margulis also share a deep concern with falsely assuming the concreteness of the metaphors and paradigms humans live through.

Haraway contributes to Margulis' work a thorough synopsis of the carefully assembled and rigorously prepared examples through which Margulis advances and supports their mutual goal of ostensibly ecological perspectives of organisms: "Organisms are ecosystems of genomes, consortia, communities, partly digested dinners, mortal boundary formations."[69] Margulis uses language that challenges conventions of unitary subjectivity, introducing a term, "body fusion'. My own research promotes the concept of paramedics and wearable technologies evolving practices, technologies, and medical ecologies by applying analogs of Margulis' body fusion processes:

> Creation of novelty by symbioses did not end with the evolution of the earliest nucleated cells. Symbiosis still is everywhere. Members of different species, and in the case of cows and corals, even from different kingdoms, under identifiable stresses formed tightly knit communities that became individuals by merger. The tales abound that support the concept that all visible organisms, plants, animals, and fungi evolved by 'body fusion.'[70]

In summary, Margulis and Haraway offer critiques of the specialization and partitioning of the many disciplines and practices affecting, and affected by, understanding of evolution and ecology. Their mutually reinforcing literature sustains my commitment to, and equips me with the means of, attending to the minutiae of concrete

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[69] Haraway. , op. cit. When Species Meet. 2007. P31-33
[70] Margulis and Sagan, op. cit. Acquiring Genomes. P56

evolutionary and ecological phenomena to guide teleparamedicine design perspectives and processes. Overall these are process-contingent tactics for mutual co-option of paramedics, body-worn telecommunications, and WEHST systems or discrete COMmand devices, which contextualize human-based computation as processes of evolution.

3.2 Field Ethnography

Figure 3.1: A field recording kit I used during field research in British Columbia.

My field ethnography included semi-structured interviews conducted from 2008 until 2012 with members of the British Columbia first responder community. Embedded within these ethnographic interviews were parallel processes of WEHST industrial design performed by both me and as collaborative design processes with research participants. I conducted these ethnographic and design processes through co-construction with interviewees of *ad hoc* scenarios supported by both question lists and loose scenario scripts. This field research with the British Columbia first-responder community demonstrated the value of scenarios to ethnographic work.

> Scenario building is a central concept in design, shifting the focus from the object to the process of communication and interaction, and covering all phases of the design process […] Scenarios are images of possible, probable, or preferable futures or futures to be avoided, and sometimes comprise the steps to achieve them.[71]

Three distinct scenarios emerged corresponding to teams of Canadian Air Force search-and-rescue technicians (SAR Tech's), ground search-and-rescue (GSAR) volunteers, and British Columbia Ambulance Service Infant Transfer Teams (ITT), as did their two overarching commonalities: first, life-and-death situations and decisions for teleparamedics themselves *and* their patients; and second, all paramedics are depicted in scenarios necessitating frequent hands-and-voice-free control of full WEHST assemblages of COMmand- coordinated control of communication by radio *and* telepresence, documentation, or "machine learning" by the combined, MEDia, PSYchophysiology, and POSition modules. Additionally, the three scenarios' requisite WEHST-level behaviors are made robust, secure, adaptive, and autonomous by WEHST assemblages also combining the POWer, HUB, MEMory, and PROcessing modules.

Scenario development participants wanted to understand what I was seeking to develop for their use in terms of tangible products. Scenarios were animated by paramedics' imaginations and populated with the skills, tools, environments, patients, and peers of paramedics. Participants would invoke examples, experiences, and particular instances, and then negotiate the parameters of their retelling to fit my stated goals and their experiences together. Reciprocal sensitivity to others' telling, and iterative retelling from, and to, multiple perspectives gave me, over time, a repertoire of

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[71] Jonas, Wolfgang. A Scenario for Design. Design Issues. Spring 2001, Vol. 17, No. 2, 2001, Massachusetts Institute of Technology, P75-76

use cases for my proposed WEHST technology. While remaining perpetually partial, these descriptions highlighted trade-specific instances where teleparamedicine was either needed, existed in a germinal state, or would not work.

Scenarios evolved concrete instances, key images, and fleeting associations, which cohered through transcripts, illustrations, coding schemes, design specifications, scripts, and storyboards. Scenarios were shared spaces for ethnographer and participants to actively design without settled agreements regarding outcomes. Scenarios could adapt within and between interviews to reflect refinements to the expectations of myself and of interviewees.

Paramedics' bodies of knowledge of "bodies in action" allowed them to easily jump up and down the levels of abstraction involved in navigating the interplay of general teleparamedicine systems requirements and particular WEHST capabilities. Scenarios, as much as, and perhaps more overtly than the discrete product they indirectly encode, continuously adapted my interview (objectives and goals) process (in terms of who, what, when, where, why, and how) by identifying and resolving problems within the purview of particular participants. Scenarios emerge throughout observations and through interviews – and designs emerge as scenarios situating a participatory and collaborative practice of bottom-up WEHST and top-down human-mediated teleparamedicine design distributed among designers, clients, and users; and supporting consideration of abandoning the concept of the human – or the individual – as the centre of design processes. Observations of the paramedic operating environment offer a tele-medical ecological ground that teleparamedicine figures emerge from.

Scenario plausibility was evaluated and verified continuously within and across interviews, and largely unfolded as weightings of probabilities of risks to paramedics' and patients' well-being.[xxxi] Cross-fertilization among scenarios occurred by changing those designs through iterative evaluation and validation for transferability and interoperability among trades. This reciprocally extended field ethnography coding and analysis into design-studio practice, while industrial design occurred throughout ethnographic contact. Scenario permutations reciprocally translated into teleparamedicine associations and assemblages of concrete WEHST modules.

Paramedics understand themselves, their patients, and other first-response trades as vulnerable to abuses of local-to-remote / paramedic-to-specialist power differentials during contemporary pre-hospital care. This influenced scenario development by reasserting paramedics' roles as active participants across hypothetical teleparamedicine processes. Scenario development permutations translated into human-mediated teleparamedicine associations and WEHST configurations. These participatory designs reflected (and partly ameliorated biases) of the research process through research material specifications sensitive to the selves-reflexivity of multisite, multimodal, multi-participant interventions.

Paramedics generally indicated how their experiences as frontline healthcare providers involve continuous negotiations of local autonomy and remote supervision. Participants were familiar with the political concerns of bodily states in real-time telemetry. Participants expressly understood teleparamedicine as a host of surveillance technologies with intrinsic risks across gender, race, profession, and class. Once participants made these associations, it was necessary to then explicitly divulge and explore WEHST's inherent ethnographic capabilities. This suite of proposed naturalistic research tactics are then reapportioned in keeping with qualitative research best-practices and attendant ethical safeguards.

Thus, the language of controversies and concerns in ethnographic research became integral to the construction and co-creation of scenarios. Scenarios continuously challenge ethnographic research material and processes to consider teleparamedicine as more than a form of surveillance, and to be complex medical ecologies including people, instruments, microbes, ecosystem, viruses, nutrients, and drugs.

3.21: First Scenario - SAR Tech's

The first scenario emerged through formal and informal contact from 2008 to 2012 with Canadian Air Force 442 Rescue Squadron search-and-rescue technicians (SAR Techs). This field contact occurred at the Comox airbase, within the Joint Rescue Coordination Centre (JRCC)[xxxii] in Victoria, British Columbia, and in some private residences.[xxxiii] The resultant scenario regarded search and rescue technicians in chemical-biological-radiological-nuclear-explosive environments.[xxxiv]

Figure 3.2: Field research with the SAR Tech teams allowed me to walk a few meters “in their shoes.”

The concerns of participants in this scenario regarding surveillance of extremely autonomous (though rigidly protocol-based) practitioners are largely grounded by my consideration of interplay of paramedic and patient autonomy. This scenario refines WEHST design by highlighting teleparamedicine impact on paramedic autonomy generally. The paramedic and patient informed consent, deception, and freedom to discontinue are interrelated.

Teleparamedicine tracks each instant of assessing and securing the stability of the helicopter. Accessing its occupants may involve conferral with remote technical specialists, which grants consent to real-time audio-visual telepresence with hybrid individual and group consent. Giving remote specialists permission to observe patients includes a host of implicit expectations, risks, and benefits. Remote participation has general, specific, long, short, individual, and group concerns about autonomy of control of degree of participation. Medical telepresence includes considerations for access to, and ownership of, media generated.

The remote specialist team shapes paramedic activity, even as they reserve intervention to respect autonomy of the paramedics. Paramedic psychophysiology, posture and environment are monitored remotely. In this case these parameters are mutually monitored among proximal search and rescue technicians' teammates to detect accidents and coordinate as a team. Deploying WEHST hardware, they commence self-tracking which includes implicit consent to participate in performance evaluation concurrent with performance monitoring and augmentation. The autonomy of paramedic plus WEHST includes voluntary and mandatory disclosures of psychophysiological, positional, audiovisual, and communication settings and states.

This scenario constrains WEHST design by concentrating on teleparamedicine-related paramedic risks and benefits. As *de facto* research participants, paramedic's assessment and withdrawal criteria include self-incrimination and consider physical well-being, psychological welfare, and participants' reputations. Telepresence-based paramedic protection and performance-optimization capabilities highlight how psychophysiological performance evaluation encompasses attention and intention tracking.

Safeguarding paramedic well-being also includes long or short baseline study of paramedic fitness. The interplay of physical and psychological welfare with professional reputation unfolds in real-time, with oftentimes indelible consequences. In these particular instances WEHST configurability balances security through surveillance of paramedic fitness versus paramedic withdrawal of particular tracking modes. Paramedics may have trepidation about being surveilled in terms of potential harms to performance or reputation. Managers have, in addition to real-time signals from the assembling team, long baseline psychophysical data from training and prior rescues. Responder data supports the composition and management of the team and the selection of a rescue strategy.

In this first scenario a train carrying hazardous materials has derailed in a mountainous area, and a hazmat crew deployed there use helicopters to sling materials to their cleanup crews on the ground. A helicopter snags their sling on treetops and crashes, suspended upside down partway down a cliff face. The aircraft locator beacon is activated, alerting the Joint Rescue Coordination Centre, who dispatches a local ground search-and-rescue (GSAR) team. A team of two search and rescue technicians at Comox airbase board a Buffalo aircraft with additional chemical-biological-radiological-nuclear-explosive personal protective equipment, and at this time they choose how to configure teleparamedicine systems and WEHST tools to suit the mission.

Deploying WEHST hardware, they commence self-tracking which includes implicit consent to participate in performance evaluation concurrent with performance monitoring and augmentation via disclosure of psychophysiological, positional, audiovisual, and communication settings and states.

Figure 3.3 SAR Tech's routinely jump from Canadian Air Force Buffalo aircraft.

Flying across British Columbia, the Buffalo arrives above the crash site. The pilot and SAR-techs' make a joint site assessment including coordinating with the Joint Rescue Coordination Centre for the Buffalo to remain on-station to relay communications from the narrow valley. They plan their extraction by helicopter and coordinate supervision with remote relay operators and specialists. Planning is balanced to best improve situational information without disrupting their work flow. Search and rescue technicians jump from the Buffalo aircraft, parachute to the ground, land safely, report their conditions, orient themselves and traverse to the crash site. At this time the Buffalo aircraft pilot is their communication relay.

Paramedics' physiological signals are extreme, both during and after jump, and then during their traverse to the crash site. These 85-kg men are carrying up to 85 kg of equipment each while wearing respirators and chemical-biological-radiological-nuclear-explosive protective and detection equipment. Arriving above the crash, they assess the site and deploy their high-angle rescue kit. They begin the high-risk procedure of lowering themselves and stretchers by ropes down to the suspended helicopter.

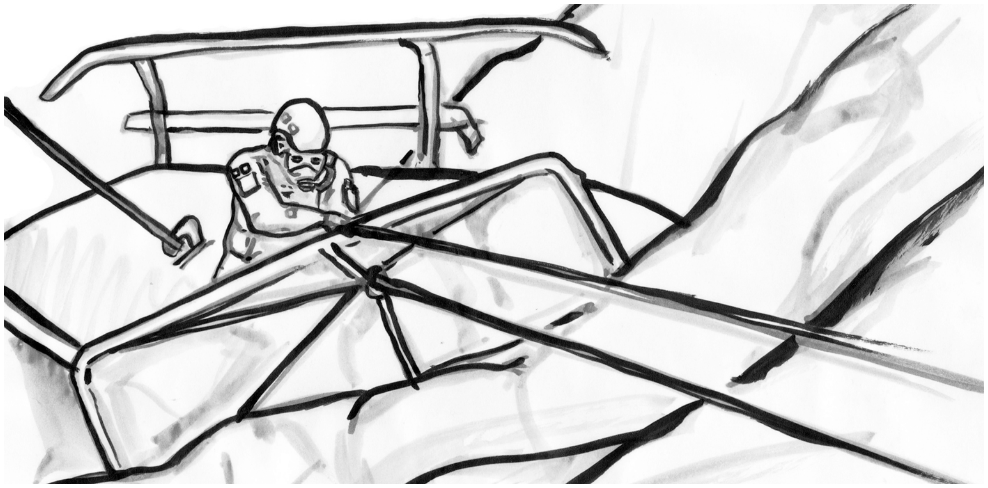

Figure 3.4 SAR Tech's conduct "high angle" rope rescue in mountainous areas.

Search and rescue technicians commence communicating with and assessing patients. The patient's teleparamedicine participation extends their medical records to the cockpit of the crashed helicopter regardless of consent. Similarly, the paramedic positional and psychophysiological signals are entangled with patient medical records. As a search and rescue technician enters the helicopter, performs triage and close assessment of the pilot and passenger, a remote team of specialists are copresent. Furthermore, there is real-time tracking and interpreting of paramedics' movement patterns along axes of static to dynamic, or rapid to abrupt. One objective of tracking these patterns is preventing serious injury or death from slipping and falling.

Patients' triage and assessment include dialogue and intimate embodied human contact between paramedic and patient, who are both at risk. Monitoring has multiple levels of deception, whereby paramedics may be cautious how they qualify signals they disclose. Revelations are to each other, to remote supervisors, and to their wearable WEHST montages. Deception is a means for paramedics to have freedom to discontinue by changing or partially dismantling the WEHST system's configuration, or manipulating their own psychophysiological signals to introduce bias into remote assessments of paramedic performance teleparamedicine. Curtailing teleparamedicine is also prudent if there are risks for coercion of paramedic by specialist (or vice versa). Furthermore, patient participation and freedom to discontinue are contingent on specialist degree of participation, and both the paramedic and patient control over this.

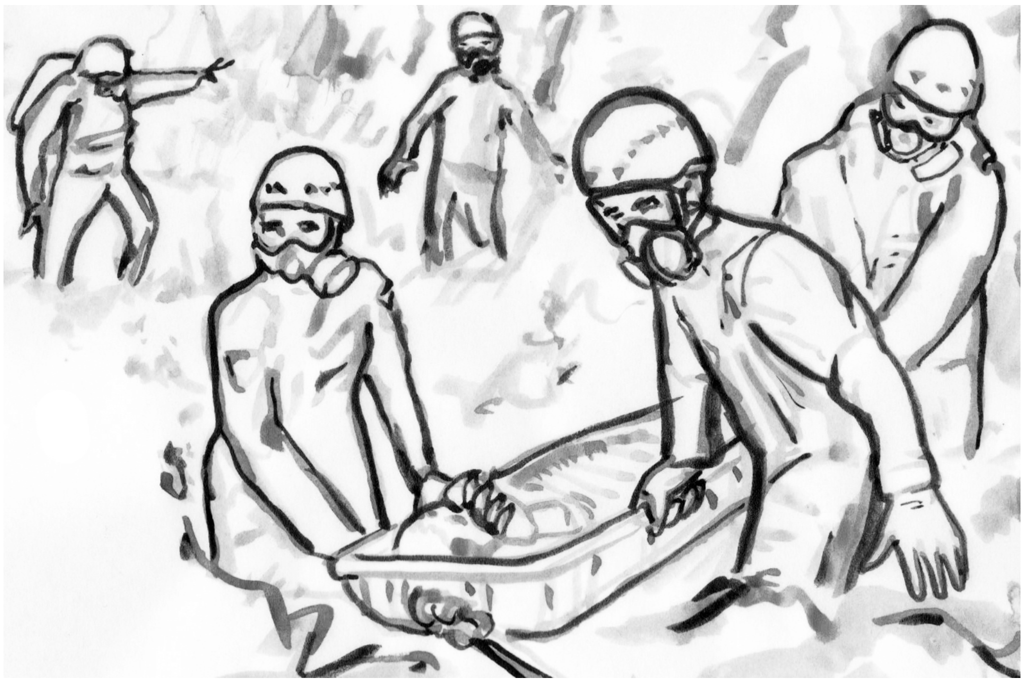

Figure 3.5 SAR Tech’s coordinate patient transfer with local Ground Search-and-Rescue teams.

Through synchronous and asynchronous teleparamedicine, paramedics coordinate with the local ground search and rescue team to plan their exit from the site. The SAR Tech team extracts patients from helicopter and into stretcher, and lower them to the now-waiting ground search and rescue team. SAR Tech’s assist ground search and rescue team to carry patients over broken terrain to a waiting Canadian Air Force Cormorant rescue helicopter. Teleparamedicine continuously monitors paramedic, patient, crash-site, cormorant helicopter, and various ground search and rescue teams for exposure to hazmat danger. Hazardous substances may be monitored in terms of: types of chemicals detected; paramedic, materiel, or patient contact with contaminated surfaces: fluctuating concentrations throughout the environment; and secondary effects such as terrain features or eddying wind directions.

WEHST monitoring of paramedics, patients and their environments continues during patient transport to the nearest chemical-biological-radiological-nuclear-explosive ready hospital. Short, medium and long-term fluctuations in paramedic psychophysiology may indicate immediate or delayed response to toxins. WEHST may also detect breaches in personal protective equipment. The partial contamination of patient and paramedics requires monitoring the interior environment of the helicopter. For instance, audiovisual tracking of surfaces and bodies touched, and matériel used, may be essential to subsequent decontamination procedures. WEHST self-monitoring includes determining how to be tested and/or decontaminated later.

Arriving at the regional hospital helipad, patients and paramedics are then fully decontaminated by British Columbia Ambulance Service and transported by ambulance into the hospital Arriving at the hospital paramedic responsibility for patient care concludes, and assessment of both patient and paramedic begins.

Teleparamedicine debriefing is ongoing during transport back to the 442 headquarters by Cormorant helicopter. Upon return to Comox, search and rescue technicians debriefing includes teleparamedicine data annotation. Multimedia teleparamedicine documentation becomes part of individual paramedic’s service and medical records. Records of both training and real calls aid both narrow, short-term performance evaluations and wider, long-term research projects.

3.22: Second Scenario - Helicopter external transport

The second scenario arises from extensive contact 2008 to 2012 in Vancouver, North Vancouver, Victoria, and Nelson, British Columbia with volunteer members of ground search and rescue community-based teams. This cohort had combined qualification for helicopter external transport systems (HETS) and paramedicine specializations.

Teleparamedicine's prospective role in this helicopter external transport systems scenario is grounded in observations made at British Columbia Ambulance Service stations, volunteer and professional fire stations, search-and-rescue stations, sitting in rescue vehicles, and visiting participants in their homes. Furthermore, I had 30+ years' experience working and playing in the same rivers, valleys, and mountains where these volunteers risked their lives. In 2010 a Beasley and Nelson Search and Rescue volunteer named Sheilah Sweatman, who worked alongside all of my interviewees, drowned during a water-rescue training exercise. In 2012 I observe the emotional toll this took on, and changes it induced in, her search and rescue community. The impact of this event underscored the extreme risks of search and rescue operations, not only near the water, but also in operations calling for helicopter external transport systems. During these particular helicopter procedures rescuers become, for a time, part of the airframe of a helicopter whose pilot may be obligated to jettison them during flight if they place the aircraft at excessive risk.

Reflexive, automatic, and remote positional feedback supports the helicopter external transport systems operators to rapidly ensure their personal protective equipment security. Similarly, biofeedback helps them self-regulate their own anxiety. This discloses the condition of their personal protective equipment and search and rescue matériel and is possibly psychophysiologically self-incriminating. Teleparamedicine enables the full team to debrief in real-time. The paramedics offer their own coding or qualifications for correspondences between their actions and psychophysiological signals.

This particular scenario is based on the experience of a close family friend (and mother of three) who in 2004 had an automobile accident in which she spent several hours of Valentine's Day trapped inside her overturned vehicle. Her car was submerged upside-down on the river bottom under the ice of the Kootenay River. She crawled into an air bubble and ate Valentine chocolate for several hours in order to stave off hypothermia. Her rescue by the *Beasley Volunteer Fire Department* search and rescue team is part of my own family's lore and a story covered by local media. Her rescue is a particular instance which the *Beasley Volunteer Fire Department* and *Nelson Search and Rescue* occasionally use to explain their tactics for cold-water and swift-water rescue. My friend, who survived her underwater ordeal, is an essential medical professional (radiology technician) who was commuting to a night shift when she plunged into the Kootenay River.

In this second scenario a hospital employee has had an accident while driving to work during a hypothetical SARS-like viral pandemic. Her vehicle comes to rest submerged upside down on the river bottom, pushed by a strong current under the river ice. This hospital employee works in a hospital caring for patients infected with the highly contagious virus. Staff well-being and activities are closely tracked. Her absence is quickly noted by coworkers and family members. Once she is reported as missing, the ground search and rescue team search the route she vanished along. Her family members, Royal Canadian Mounted Police and ground search and rescue search the entire 20-km route several times before spotting faint tracks leaving the road, continuing down a steep embankment and leading to a dark hole rent in the river ice. The headlights of her submerged car are barely visible through the thin but treacherous ice covering a deep river channel.

Figure 3.6: Extreme geography challenges the of British Columbian volunteer ground search-and-rescue (GSAR) community to respond in settings combining cold-water rescue, swift-water rescue, helicopter external transport, and chemical-biological-radiological-nuclear-explosive personal protective equipment.

Figure 3.7 Helicopter external transport systems (HETS) enable search-and-rescue operators to clip onto a long tether attached to the belly of (and become practically, legally, and ethically part of the airframe of) a helicopter.

A ground search-and-rescue cold-water rescue team is dispatched by the rescue manager, and teams from multiple agencies converge on the accident scene. Before the manager arrives on-scene, the teams receive media from the site. They decide to deploy a helicopter external transport systems team to reach the other side of the river channel, where there is more open water and is closer to the vehicle. The team assembles a kit of rescue matériel suiting the physical conditions and chemical-biological-radiological-nuclear-explosive risk. The helicopter external transport systems team coordinates their roles while in transit to the scene. Upon arrival, the whole team assesses the site while gearing up for an extremely risky rescue. They face the uncertainty of whether this is a rescue or a body recovery. Police, provincial emergency response agencies and the rescuee’s family members make their own contributions to the assessment and coordination process. The rescue managers assess the teams’ preparedness and willingness to undertake this risky rescue.

Rapid team selection allows a first helicopter external transport systems operator to clip onto the helicopter longline as soon as it arrives on scene. They are lifted from the roadside and across the river. Reflexive, automatic, and remote positional feedback supports the helicopter external transport systems operators to rapidly ensure their personal protective equipment security. Similarly, biofeedback helps them self-regulate their own anxiety. This also discloses the condition of their personal protective equipment and search and rescue matériel and is possibly psychophysiologically self-incriminating. The helicopter delivers the first paramedic, slings in winches, lights and matériel, and then longlines a second paramedic in. The two paramedic's asses the risks and plan a response while configuring their own personal protective equipment. They assemble their rescue and self-rescue equipment with remote supervision by managers and teammates.

The two paramedics establish tightly coupled telemediation through voice, psychophysiology, and positional modalities, and one paramedic enters the water. Wearing self-contained underwater breathing apparatus (SCUBA) and a dry suit, this person breaks through the thin ice and approaches the submerged vehicle. Swimming down to the vehicle, the paramedic attaches a tether and assesses the vehicle stability before examining it closely. The paramedic discovers that the driver has climbed into an air pocket and may be alive. The paramedic returns to the surface and coordinates a response plan with the team.

While one paramedic waits in the water, the second paramedic operates a winch and draws the vehicle up into the shallows where it is only half submerged. A second tether is attached to the vehicle to stabilize it. The first paramedic is now recalled from the water as their WEHST ensemble detects that they are trending toward hypothermia and are unable to safely continue. They switch roles. The second paramedic dives shallowly under the water, secured by a self-rescue tether, and opens the car's mostly submerged rear side door. The rescuee is freed from the back seat of the vehicle where she had crawled into an air bubble. The rescuee, now a hypothermic patient, is only partially conscious as she is pulled to shore. The paramedics remain in their cumbersome wetsuits and respirators as precaution against viral infection. Dried, wrapped, warming-up and placed into a stretcher, she is rapidly assessed and stabilized by paramedics. The helicopter approaches, hovers, and a longline from it is attached to a paramedic and the stretcher.

Paramedic and patient are lifted and carried by the helicopter to the British Columbia Ambulance Service ambulance waiting at the roadside. The helicopter returns to extract the second paramedic and the equipment. The hypothermic patient is loaded into the ambulance by paramedics wearing chemical-biological-radiological-nuclear-explosive personal protective equipment. The two paramedics are thoroughly decontaminated before leaving the scene, and presenting themselves for transport to a quarantine facility for 72 hours. WEHST continues physiological tracking to facilitate early detection of possible injury or infection symptoms.

Teleparamedicine enables the full team to debrief in real-time. The paramedics offer their own coding or qualifications for correspondences between their actions and psychophysiological signals.

3.23: Third Scenario – Infant Transport Team

The third scenario regards overall a chemical-biological-radiological-nuclear-explosive mass-casualty incident (MCI) response. This scenario emerges through my contact with the British Columbia Ambulance Service Infant Transport Team (ITT), the Justice Institute of British Columbia (JIBC), and Emergency Management British Columbia. Infant Transport Team practice-based teleparamedicine in this scenario was based on extensive fieldwork. I spent time at the Justice Institute campus and immersive multimedia simulation centre. I participated in advanced life-support (ALS) "ride-alongs" from the lower mainland as a 'third' – the third member of a paramedicine team. I also participated in infant transport team "ride-alongs" in ambulance, command vehicle, helicopter, and airplane transports crisscrossing British Columbia. The infant transport team brought me in and out of British Columbia Women and Children's Hospital pediatric emergency room, intensive-care unit, and infant transport team headquarters.[xxxv]

The balancing of authority and autonomy in pediatrician's long-distance supervision of infant transport team paramedics showed a mutual support by these two professions only partly attributable to their very early adoption of telehealth-led practice. Their adroit telehealth also emerges from and nurtures deep, long-term bonds between infant transport team members and their pediatrician partners. These bonds are rooted in these paramedics' intimate proximity to the pediatricians, nurses, patients, and families at British Columbia Women and Children's Hospital, where the infant transport team is headquartered. My observations of the infant transport team, both from inside their orbit, and from alongside their deeply respectful peers from multiple first response trades, showed them as a distinctive community of deeply idiosyncratic individuals.

This community adopted telehealth early because of their deep personal commitments to being close and maintaining long-term relationships with their patients, patients' families, nurses, pediatrician peers, pilots, and first-responder partners. This was brought home for me when I saw a veteran infant transport team paramedic returning daily to the bedside of a six-year-old gradually revealed to be brain-dead whom they had transported four days earlier. The 35-year veteran paramedic was with the family, nurses and doctors every day. He, his partner, and many colleagues participated in a hasty and harrowing telecommunication- and teleparamedicine-intensive transport from the mountainous Okanagan region of Interior British Columbia. Subsequently they daily traversed a few steps' distance from infant transport team headquarters to reach the life-supported child and family in the pediatric intensive care unit.

This scenario is oriented at responses at the level of the infant transport team as a community of practitioners. These three sub-scenarios advance COMmand and WEHST design by evaluating how informed consent is influenced by teleparamedicine. Telehealthcare interventions require informed consent by vulnerable groups, for necessary deceptions, risking heinous discoveries (such as abuse, illness, and crime), and changing levels of confidentiality.

> Children are not little adults. Their physical, emotional, and social development is different, they are far more exposed and vulnerable, and their coping abilities and needs

> in times of crisis are not the same. It is for this reason that children require treatment tailored to meet their needs.[72]

Infant transport team contribution to a joint response capability is significantly different from other trades. For example, children's closer proximity to the ground and high respiratory and metabolic rates increase their exposure to particulate contaminants and, "places them at higher risk for the development of cancer following exposure to radioactive substances."[73]

Infant triage considers parents and siblings of injured infants, not just as a matter of compassion but as a practical part of good care toward good outcomes. "The issue of family connection when caring for children is most important: When a child is injured, the whole family is affected as a unit."[74] On-site decontamination of infants, mothers and pregnant women is conducted and requires different processes than for adults. "Children will require unique considerations for disaster planning: staff training, equipment, guardianship, identification, and notification and reunification of families."[75] Paramedics conduct triage and decontamination wearing class-III personal protective equipment. Working exhausting 35- to 45-minute shifts, they place themselves at risk of heat stress. Paramedics require periodic mandatory rest periods and close teleparamedicine psychophysiological monitoring.

Patients and their families, and paramedics and their families, are vulnerable groups giving implicit consent; to living together with work-related psychological

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[72] Rassin M, Avraham M; Nasi-Bashari A, et al. Emergency department staff preparedness for mass casualty events involving children. Disaster Management & Response 2007 Apr-Jun; Volume 5, Issue 2. P36

[73] Op Cit. Rassin et al. 2007 page 37

[74] Op Cit. Rassin et al. 2007 page 42

[75] Timm, N. & Reeves, S. 2007. A Mass Casualty Incident Involving Children and Chemical Decontamination. Disaster Management & Response, Volume 5, Issue 2. P54

stresses and offering each other some means of ameliorating associated post-traumatic stress disorders.

The third scenario regards overall a chemical-biological-radiological-nuclear-explosive mass-casualty incident (MCI) response. In this first infant transport sub-scenario a dirty nuclear bomb is detonated in a crowded public space in Vancouver. Containment of contaminated people and materiel comes before decontamination. Infant transport team contributes to coordinated fire, chemical-biological-radiological-nuclear-explosive, police rescue by transporting blast injured and radiation-contaminated infants, children, mothers and pregnant women to British Columbia Women's and Children's Hospital.

Figure 3.8 Infant Transport Team members are the only paramedics qualified to independently asses and care for infants, children, pregnant women, and new mothers. In large-scale chemical-biological-radiological-nuclear-explosive response settings the infant transport team care would be compromised by wearing personal protective equipment.

Infant transport teams converge on the site along with other trades and coordinate teleparamedicine-supported triage of infants and their families. Throughout the emergency response synchronous and asynchronous monitoring occurs on the body and remotely as audio-visual and environmental signals, and is recording supplemented by psychophysiological and communications data. British Columbia Ambulance Service ambulances circulate continuously for hours, transporting several hundred patients with mixed blast injuries and varying degrees of nuclear contamination. Infant transport teams conduct teleparamedicine via COMmand, MEDia, PSYchophysiology, and POSition sub-systems to document their response, and track and reduce secondary contamination of emergency infrastructure and first response personnel.

Figure 3.9: The infant transport team conduct intraurban, interurban, and inter-regional transport of women with high-risk pregnancies. Triage of pregnant women during mass-casualty events would be the purview of the infant transport team.

The second stage of this third scenario is in the interurban transport of women with high-risk pregnancies in the 24 to 48 hours following the attack. A particular instance is a young mother of a two-year-old, having premature contractions during her second pregnancy. She is in a small Sunshine Coast town, separated from Vancouver by two ferries. She needs infant transport team transport to a hospital with advanced obstetric care beds available during this provincial emergency.

The responding two-person team physical and emotional fatigue is high, and they are on average older than other British Columbia Ambulance Service trades. The mutual support and co-monitoring of the infant transport team partners is supplemented by teleparamedicine monitoring. If required, paramedic performance is augmented via biofeedback and enhanced situational awareness.

These partners fly from Vancouver to the small hospital on the Sunshine Coast, land on the hospital helipad. They enter the hospital, debrief, and banter with local British Columbia Ambulance Service primary care paramedics and nurses. They make a humane introduction and qualitative assessment, get the patient records, get patient records, and make a quantitative assessment. With assistance of the helicopter aircrew they transfer the patient to a stretcher. She is shuttled to the waiting helicopter and settled aboard. Lifting off, and flying toward a regional hospital on Vancouver Island they are, more than ever, reliant on guideline-based care to save lives, time, money, and human resources.

Specialists are in high demand and perhaps slow to respond. This increased paramedic autonomy, combined with fatigue and health-care system-level disarray has them continuously asking themselves, “What did we miss?” Applying the precautionary principle is reinforced by fully wearable multimodal synesthetic biofeedback and multimedia documentation. These practices constitute a juncture of paramedic surveillance, sousveillance, and self-monitoring.

Figure 3.10: Inter-region transport of non-critically ill children is both an infant-transport team responsibility and an opportunity for a relatively older cohort of paramedics to rest and recuperate, debrief, and bond, The physical and emotional demands of their trade make them vulnerable, while reinforcing tight bonds among teammates.

The third stage of this third scenario is inter-region transport of non-critically ill children from overwhelmed Vancouver hospitals to regional hospitals with available beds. Most of these transfers return children to their home communities discharged earlier than scheduled due to the crisis. In this instance, two infant transport team paramedics are simultaneously transferring a three-day-old neonate and mother, a two-week-old pediatric patient, and a two-year-old infant with her father. Patients are transported by ambulance to the air ambulance hangar in Richmond.

The patient transfer from British Columbia Ambulance Service basic life support ambulance paramedics to the infant transport team and aircrew is rich in professional and personal dialogue between paramedics and aircrew. Their multisite logistical coordination and communication is about the patients, their medical records and histories, and other documents. Patient transfer concludes with the air ambulance flight crew physically transferring patients. As this is a routine transfer, patient contact is kept to the minimum necessary monitoring during flight. In-flight the infant transport team catch up on paperwork, debrief each other, and even nap.

Figure 3.11: Teleparamedicine research also protects paramedics by investigating concerns for paramedic and patient autonomy presented by teleparamedicine. Paramedics relationships among, and with, themselves are key to surviving the hazards and stresses of their job.

Landing in Kamloops, the neonate and child are transferred to the British Columbia Ambulance Service pickup crews who will take them to the local hospital. Back in the air and *en route* to Salmon Arm, the physical and psychological stresses of day-three post-event are acute. Stress affects infant transport team partnerships, dispatch, aircrew and pediatricians, and the medical community.

PSYchophysiology monitoring gives dispatchers the quantitative data needed to evaluate and manage the infant transport team closely enough to forestall or ameliorate burnout and to assist in recuperation. In this case it may mean asking a 40-year British Columbia Ambulance Service veteran to meditate or nap in-flight instead of filing paperwork. Infant transport teams widely self-report their peak performance was as communicating with a minimum of spoken communication, even silence. In these instances of subtle communicative competence PSYchophysiology and POSition data may be coupled to augment paramedic teams' self and mutual assessments.

Local and remote peers and WEHST collaborate to buffer infant transport team stress until they deliver patients to Salmon Arm; whereupon they are asked to fly to Whitehorse, Yukon Territories instead of returning to Vancouver, and the race continues.

3.3 Laboratory Research

What I learned from field ethnography and practice-led observations of, and in laboratories is how all research is collaborative. Individual researchers successes benefits others through new knowledge creation, training new researchers, or allocating community-level resource, However, the most relevant observation I made was how researchers who work towards advancing other researchers' goals may equally advances their own.[xxxvi] This is particularly in areas of research instrumentation design, which have deep relevance to creation of new knowledge in basic, applied, and clinical research areas. Working for, and with, others can advance research even when conventional research resources are absent. Helping others also aids those offering support. This entails mutuality among research streams, much as Haraway emphasizes mutual responsivity between researchers and research subjects.

Considering individual research programs as the different studies whose multiple results are a pool contrasted and combined to advance wider meta-analyses identifying patterns within and among research paradigms. This distributed and decentralized conception of research explicitly takes numerous research environments as individual (qualitative and quantitative) data points used to test – and refine – the scientific method. Considering research environments as actors participating in meta-analyses translates into design guidelines for reflexive research capabilities at both the level of design of research programs, and as industrial designs of particular “things” as deliberately embodying reflexive research capabilities. Therefore I approached teleparamedicine and WEHST industrial design as a complex system of research instruments – a nominal socio-technical ecosystem – emerging from the confluence of many disparate researchers’ projects.

The lab is a place for focused – and shared – inquiry into the irreducible complexity underpinning scientific cause *and* effect. Laboratory-based learning of human anatomy, physiology, and cellular biology included explicit instruction in how laboratory practices is permanently partial, biased, and contingent, and continuously establishes and dismantles models of the interplay of cascading physiological and intracellular processes.[xxxvii]

Several months after entering university in 1998 my personal life-long relationship with medical laboratories began in earnest. I self-diagnosed, and underwent surgery, with no chemotherapy or radiation treatment, for malignant cancer. This commenced 15 years of intensive follow-up in hospital labs, giving blood, receiving scans, engaging with lab technicians, and learning not just terminology and numbers for procedures, but also the who and how of tests and results given and received through embodied practices.

Five years later, in November 2004, I had emergency major open-heart surgery. My aortic valve was replaced with a titanium valve. My body temperature was reduced to 17 degrees Celsius to stop brain metabolism. The carotid arteries supplying my brain with blood were detached from my transverse aorta. My heart and brain were both stopped and I entered suspended animation for 18 minutes on the operating table. During this pause my ascending and transverse aorta were replaced with a knit textile graft. Preceding and following this surgery were incessant visits to – and interminable time in – medical laboratories. This continues today, as almost 400 vials of my blood and close to fifty cardiac ultrasounds have passed through hospital labs to share their secrets with me, teams of hospital and medical technicians and nurses, and with specialized physicians. These confidences are also divulged, with varying degrees of anonymity, to researchers whose research designs may continuously find new results and questions within their recirculating tests and numbers. The black box of my heart punctualized and depunctualized in labs.

In 2005 to 2008 I entered employment as a laboratory research assistant in earnest. My internships and medical encounters within laboratories advanced my own research projects by inserting my research design process into wider actor networks of specific researchers, instruments, literatures, materials, and infrastructure. Commencing in Hexagram's *Université de Montréal Formlab*, I immediately discovered answers to my questions about the role of theory and practice in industrial design research.

These experiences in academic labs taught me the value of theory to practice, the value of constructivist approaches to technology-oriented projects, and of approaching wicked research and development problems through research-creation. Together these jobs taught me how working for and *with* others advanced my own research more than forging ahead alone.[xxxviii] For example, in 2008 and 2009 I worked as a researcher for Dr. Andre Achim at the *University of Québec a Montréal* (UQAM) neuropsychology department to develop and continuously improve the wearability brain-computer interface for laser optode-based hematoencephalography (HEG). By attending to the minutiae of clinician and patient ergonomics this project aimed to change the wider neuropsychology research community's access to infrared brain-imaging tools and data.

Hematoencephalography technology's potential for application to brain-computer interface and neuroprosthetics brought my attention to embodiment as messy and plural even on the level of the scalp or individual optodes. This project identified how embodiment-led design of research tools presents a means of practice-led industrial design research to answer research design questions. This research project also highlighted particularities of neuropsychological research paradigms as double-edged in their quest for truth by ignoring the agency of technological actors and these actors' profound capacities to reciprocally transform humans. This particular emerging research modality was "messy" in that it demonstrated many of the contradictions and complications of the competitive and somewhat arbitrary process of interleaving theory, hardware and software technology, and clinical practices into an emerging mode of research.

In 2007 I entered continuous full-time professional practice in commercial research labs with active research and development programs for research-matériel based upon electronic textiles, psychophysiological sensing, and wearable computing.[xxxix] My work was in intelligent textile research and development in the *Centre-de Transfert de Technologie/ Fashion Technology Transfer Centre* (CTTM) laboratories. This academic-industry technology transfer lab connected in real-time to thousands of small, medium, and large businesses.[xl] Professional practice developing research and development matériel created opportunities to advance my own practice-based research within teams working always in relation with clients.

Embracing end-users as action research co-participants, giving embodiment as concrete foundations of research, bears out their "experience and worldviews in the theoretical models that guide practice and policy."[76] Working for and with clients who are predominately practicing professionals who integrate research is a basis for "evidence-based practice".

Undertaking research and development in the *Techno-Espace* garment industry technological development laboratory taught me about joint industry, academic, and government partnerships. Clients included artisans, professionals, and neophytes in different apparel industry sectors who needed *Techno-Espace* to consolidate multiple technical, management, and research resources. I experienced firsthand how in a

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[76] Brown, Leslie & Strega, Susan. Research as Resistance: critical, indigenous, & anti-oppressive approaches. Canadian Scholars' Press, Toronto. 2005. P12

hostile economic environment academic-industry-government partnerships contribute to innovative socio-technical analyses. However, for garment and textile industries to brave the risks of innovation was possible only if laboratories unambiguously linked new knowledge creation to economic development with concrete benefits for producers with payrolls, rent, and taxes to pay.

From 2010 to 2012, I worked part-time for *Janro Imaging Laboratories* (JIL).[xli] This laboratory (JIL) is a commercial research and development laboratory where I collaborated in designing 3D motion-tracking-based interface tools for producing hand-drawing stereoscopic animation content. Two years of part-time research within *Janro* gave me experience with gesture-based control of computer-vision systems. Developing these systems closely coordinated a multidisciplinary design, engineering, computer science team with talented animators testing hardware and software. Coordinating these user trials offered experience in garnering immediate and tangible ethnographic fieldwork inputs into designing tangible interfaces. The first year of industrial design research was in close collaboration with a multidisciplinary team.

After one year *Mitacs Accelerate* research internship funding was arranged to continue further *Janro* research and gained access to industry and academia perspectives on government funding bodies' role in research and development. Differences in tempo, focus, priorities, accountability and tangibility of outcomes, between industry, academia, and government, all spoke to the wide spectrum of research ethos, attitudes, and expectations by partners of each other, and of themselves.

Academic researchers approached *Janro*'s products as a technical platform to repurpose as a research platform; however, the university administration was almost incapable of coordinating the industry-academia model in terms of deadlines, clear communication, or overseeing the research assistant payroll. *Janro*'s research and development team refined their in-house research platform into a self-sustaining and progressively commercially viable technical platform.[xlii]

Figure 3.12: Janro Imaging Laboratories developed SANDDE software to produce hand-drawn stereoscopic animation. This software is controlled using 3D motion-tracking interface tools.[77]

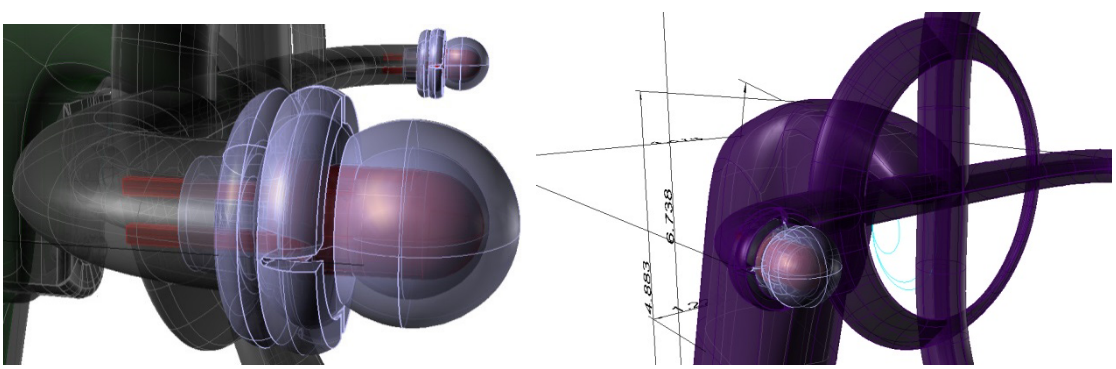

Figure 3.13: Industrial design of a rapid-prototyping manufacturable (selective laser sintered nylon) controller for the SANDDE software was guided by ethnographic studies and extensive field trials; and in parallel with refining the software for commercial release.

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[77] Downloaded December 2014 from: http://research.ecuad.ca/-/uploads/sites/2/2013/07/IMG_0185.jpg; and http://research.ecuad.ca/-/uploads/sites/2/2013/07/IMG_0182.jpg

Beginning in 2009 I have worked continuously as an industrial design researcher for *Thought Technology Ltd*. in their biomedical instrument research and development lab. *Thought Technology's* product line has focused for forty years on biofeedback and neurofeedback usability, portability, and wearability within clinical environments and as a platform for conducting evidence based research protocols. Product development at *Thought Technology* encompasses all aspects of research design, design specification, user requirements, technology development, sales, marketing, support, training, and in-house manufacturing.

Multidisciplinary team-based practices of translating client demands and user needs into concrete manufacturable hardware, software, and firmware toolsets involves parallel research basic, applied, and clinical requirements. Within a multidisciplinary in-house laboratory industrial design is progressively moved further upstream in the research and development cycle. Industrial design links business cases with applied, clinical, and basic research for design, biomedical engineering, electrical engineering, computer science, and mechanical engineering. Industrial design coordinates product marketing and technologies with multiple clients' demographic, physiological, ergonomic, biomechanical, anthropological, and anthropometric aspects of dynamic bodies in motion.

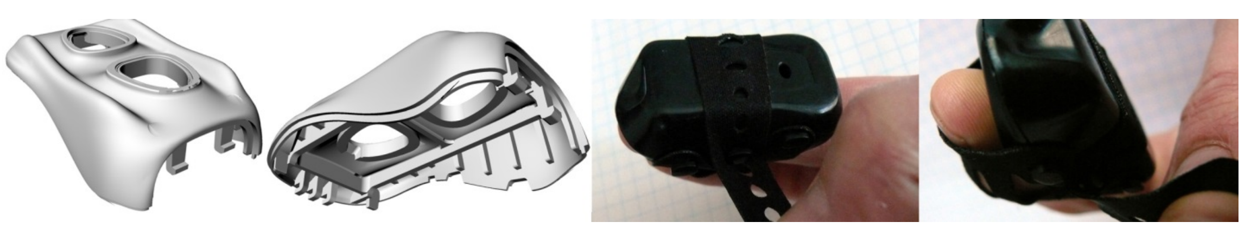

Figure 3.14 The EVU-TPS Wireless performs sensor fusion of skin conductance, pulse, respiration, and temperature modalities. 2013

Figure 3.15 The Microinfiniti is a multimodal encoder for recording a wide spectrum of psychophysiological signals. 2014

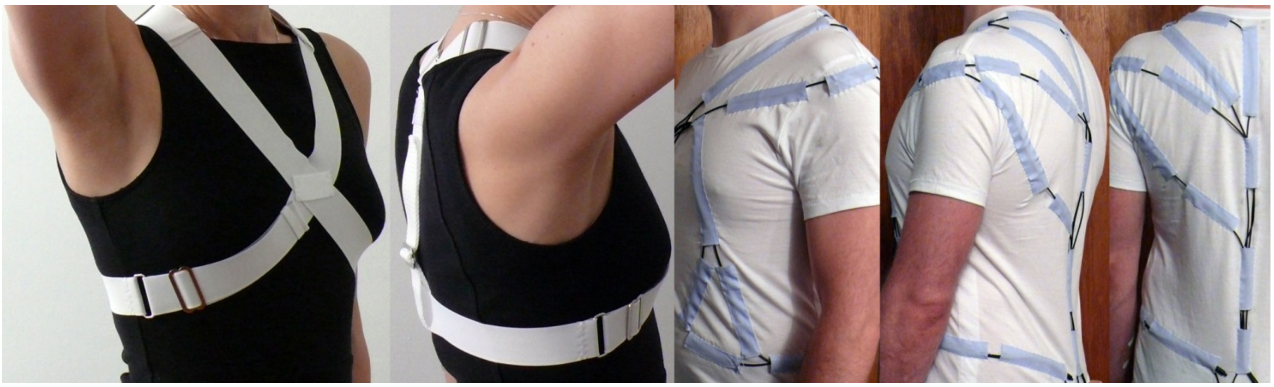

Figure 3.16 Wearability considerations for sensors and stimulators, cabling and connectors, and wearable computers are part of the basic, applied, and clinical research design process for designing commercial instrumentation. 2014

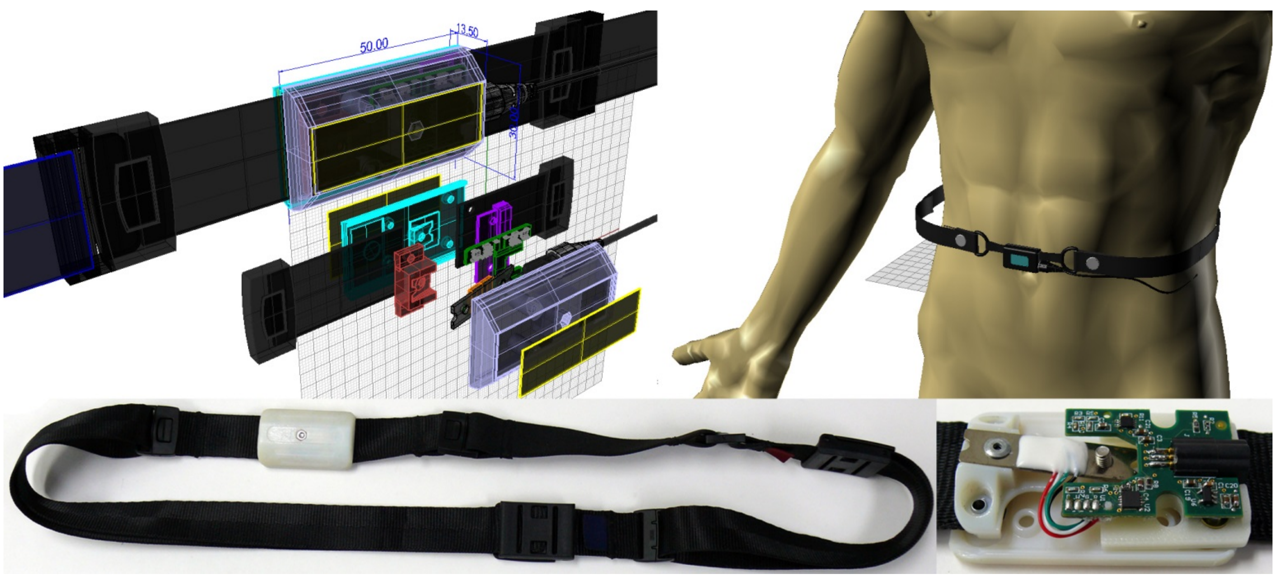

Figure 3.17: A set of images representative of the development process for a mass-manufacturable Thought Technology Ltd. Respiration Sensor for clinical and research environments. 2014

Psychophysiological clinical and research instrumentation research practice brings my attention to changes induced in bodies' usage of *networked* tools; wherein psychophysiological biofeedback tools are research instruments tuning this network of a particular body's interplay of multiple physiological subsystems, towards networks of many bodies, and then orienting tools to wider technical networking environments. Taking this design research work as atheoretical (ANT) processes of social and technical analysis is attentive to signals as constantly deformed in transport, inexorably delayed, and fully mediated.[78] Therefore, technical instruments accessing and assessing information about bodily states require fine-grained discrimination among those discrete actors comprising physiological subsystems and psychological states. This work in developing cutting-edge research material includes reciprocal academic-industry transfer of technology and ensures maximum impact on multiple research fields.

3.4 Studio Research

This section describes how my design research includes a studio was recognizable as a workshop or atelier in which a particular subset of specialized design practices' occurrence was contingent on a particular set of tools becoming available.

Studios embed projects and extend cognition much as an ecosystem. The studio may be the minimum group of elements for self-sustaining mental modeling and simulation processes of complex[xliii] system-level relationships and speculation on multisensory experiences. My design studio practice made incursions into dance, movement, and meditation studios. Rhythmical or irregular, choreographed or

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[78] Latour, op. cit. On Recalling. ANT. 1999. P15

improvised, voluntary or involuntary, gross or infinitesimally fine, bodily movement entrained and amplified design choreographies. Built upon hardwood floors, and punctuated either to the tempos of a musical and muscular score or on silence. Studio practices identified and resolved design dilemmas in bodily “flow-states.” Peak cognitive performance permitted non-linguistic visualization and dynamic mental simulations which discovered and uncovered new associations.[xliv]

The design studio was more than a place. It was a posture of reflexive attention to gross movements in the dance studio and fine perceptual movements in the meditation studio. Similarly, my professional biofeedback instrument design practice explicitly aimed to amplify attention to embodiment. Augmenting biofeedback with movement and meditation practices sensitized me to, and enhanced control of, processes describable as heart rate, respiration, skin conductance, temperature, electromyography, electroencephalography, electrocardiography, and electrooculography signals. However, the studio did not exclusively promote design of human embodiment-centred products and processes. Studio environments amplified and honed my concentration and enabled me to conduct mental design processes for, through, and into (with acknowledgments to Sir Christopher Frayling and Herbert Read)[79] complexes concerned with processual phenomenon irreducible to paradigms.

Designing these physical products – WEHST – was not confined to classical studio settings. Design arose anywhere, anytime, through visualization and mental efforts manifested a clear and evolving model. Dynamic neural-embodiment-based

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[79] Frankel and Racine, op. cit. The Complex Field of Research. 2010. P4

processes enable me to create multiple concepts I touched, felt, heard, moved and wore. An extended sensitivity incorporated the physical materials, servos, batteries, processors, wiring harness, fasteners, straps, and display elements. This innervation manifested as constellations of bodily phenomena of my own bones, muscles, nerves, skin, and blood. Studios also situated imagined environments and its attendant creative accidents less rigorous – but more vigorous – than laboratory practices. Studios embedded and extended my embodied industrial design skillset of drawing[xlv], sculpting, prototyping[xlvi], diagramming, and meditatively visualizing and simulating. Studio-based design processes invited discoveries by offering concrete paper, clay, and living tissue as scaffolds embedding and extending body-centred design processes. Findings included new embodied knowledge creation, discovery of innovative relationships, and creation of a novel class of actors.

Chapter Four: Wearable Technologies, Designs, and Designers

4.1: Contemporary Wearable Telepresence Technologies

Existing wearable telepresence technologies need to be adaptive and distributed enough to be inconspicuous and unobtrusive for the wearer to use in relative comfort. At the same time, wearable telepresence is a form of surveillance *among* paramedics, patients, toolsets, and environments and raises a host of ethical concerns.[xlvii]

As I discuss in this chapter, the need for a system like WEHST is because contemporary *ad hoc* assemblages of mobile videoconferencing and telecommunications technologies are currently inadequate for use by individuals or for whole body systems. Current off-the-shelf wearable technologies (such as combinations of Cisco systems telepresence software, generic smartphones, and GoPro camera systems) are not able to collect and transmit accurate signals or process the feedback of multiple parameters and participants without being flagrantly obtrusive –unwearable.

The wearability of any telepresence technology arises from the interplay of voluntary and involuntary paramedic speech, gesture, and physiological states.[xlviii] Enacting real-world situated wearable telepresence balances what is *desired* (and imagined) versus what is *required* at levels of: hardware and software technologies' sites on the body, and positions in the environment. To be wearable one must balance device ergonomics (including size, weight, position, temperature, and texture) against continuous bodily and environmental instabilities. Wearability is made more robust by active and passive means of reducing signal distortion introduced from bodily, technology and environmental sources.[xlix] Adequately wearable systems should buffer bodily perturbations (physiological and biomechanical) and environmental fluctuations (chemical, mechanical, electromagnetic, and thermal).

The various situations encountered by paramedics working in hazardous and risky conditions across multiple telehealth sites obliges the designer to minimize the load on the working memory[80] of any device.[l] Ongoing adaptation of a “wearable” requires coordinated decentralization of information to ensure stability and control at different levels of the system in play- and by all of those entangled in the decision-making process. Wearables are assemblages of different actants, to use Latour’s term, in interactions among local and remote telehealth sites. Wearability challenges the boundaries of where the paramedic self begins and ends, in interaction with others, and as one is in collaboration with information-gathering machines.[li]

Unobtrusively collecting, transducing, and sending accurate simultaneous signals with multiple parameters from ambulatory participants is difficult. For this reason teleparamedicine wearability involves creating devices that can provide ongoing customization and personalization.[lii] Wearability, in other words, can be understood as a type of emergent behavior coordinated through a “rule set” that is limited by the discontinuous central coordination amongst bodies, emerging technologies, evolving practice strategies and goals, and volatile environments.

The individual personalization of a wearable system means attentiveness to the collective movements and actions of a plurality of self-directed entities. This collective

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[80] Robbins, Philip and Aydede, Murat. The Cambridge Handbook of Situated Cognition. Cambridge University Press. 2009. P6

behavior is nominally a form of "flocking".[81] Wearability considered as flock cohesion (or swarm, herd, or school) understands the paramedic as an embodied being embedded in a particular environment and extended in telemedical ecosystems.[liii]. The emergence of a minimal rule set enables a flock to continuously optimize its organization and coordination of its movements. In terms of the production of wearable devices, industry-standard mass-manufacturable electro-mechanical components and sub-assemblies are becoming flexible and granular to be able to operate at different scales. Devices with distributed architectures enable combinations and configurations of garments or personal protective equipment.

Wearability does not confine the generation of information to an individual paramedic's person.[liv] Wearable technologies require paramedics, patients, and remote specialists to contribute their perceptions and thoughts collaboratively to identify problems and to create solutions.[lv]

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[81] Hemelrijk, Charlotte K. and Hildenbrandt, Hanno. Some Causes of the Variable Shape of Flocks of Birds. PLoS ONE, 6(8). 2011.

Figure 4.1: Wearable teleparamedicine technology compatibility with chemical-biological-radiological-nuclear-explosive personal protective equipment is a shared responsibility.

4.2 Operating as design competitors

Contemporary product systems leave gaps in the teleparamedical ecosystem niche that are addressed by my proposed WEHST-based human-mediated teleparamedicine system. However, as networks of devices (Latour) WEHST's position upstream or downstream of competitors respectively subsumes or augments those challengers. The three competitors considered here are the *parasitic humanoid* non-commercial platform technology for wearable robotics research, the *Audisoft* mobile video communication commercial platform, and the multiple international "future soldier" programs.

Parasitic Humanoid

The *parasitic humanoid* is both a competitor and a particularly prescriptive technology. Created by Taro Maeda (et al.) at Osaka University in 1990, it was first developed as a non-commercial platform technology for wearable robotics research. The refinement of the *parasitic humanoid* is ongoing through parallel research streams of wearable computing, symbiotic interaction, human behavior, and telepresence.

Maeda et al. characterize the *parasitic humanoid* as an anthropomorphic "wearable robot as a behavioral interface without powered assist,"[82] and differentiate their approach from anthropomorphic autonomous[lvi] or exoskeletal human-operator-worn robotic architectures. The *parasitic humanoid* contrasts sharply with competing architectures of electromechanically actuated humanoid robots – the *parasitic humanoid* is several orders of magnitude lighter than a humanoid robot, with equivalent improvements power efficiency.

The *parasitic humanoid* offers no mechanical power to its wearers but, as Iizuka et al describe, it "is safe and light for the wearer, and can assist him or her with rich behavioral information, when the worn robot is continuously capturing, modeling, and predicting the behavior of the wearer."[83]

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[82] Iizuka, Hiroyuki; Ando, Hideyuki; and Maeda, Taro. The Anticipation of Human Behavior Using "Parasitic Humanoid". Department of Bioinformatics Engineering, Graduate School of Information Science and Technology, Osaka University. Human-Computer Interaction, Part III, HCII 2009, LNCS 5612. Jacko, J.A. (Editor): Springer-Verlag Berlin Heidelberg. 2009. P 285
[83] *Ibid*

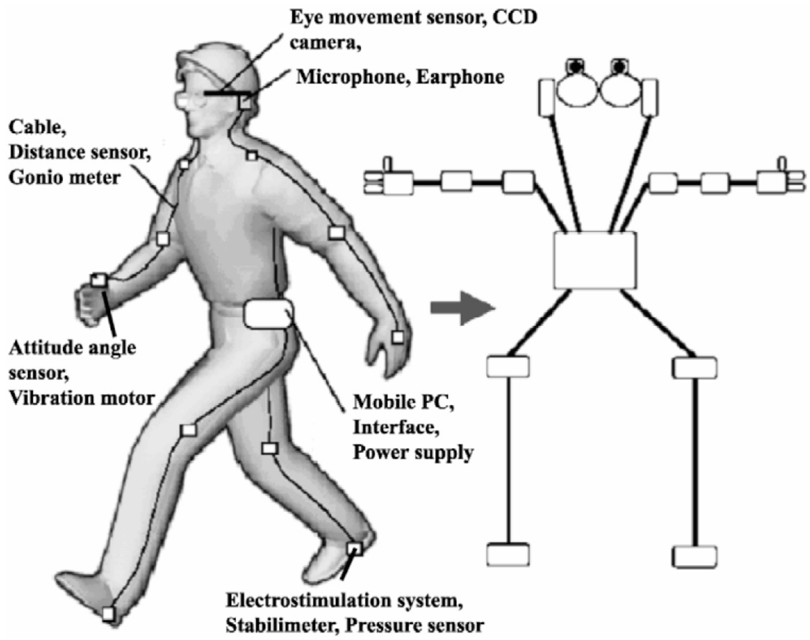

Figure 4.2 Parasitic humanoid sensory devices construct a wearable humanoid without muscle or skeleton. [84]

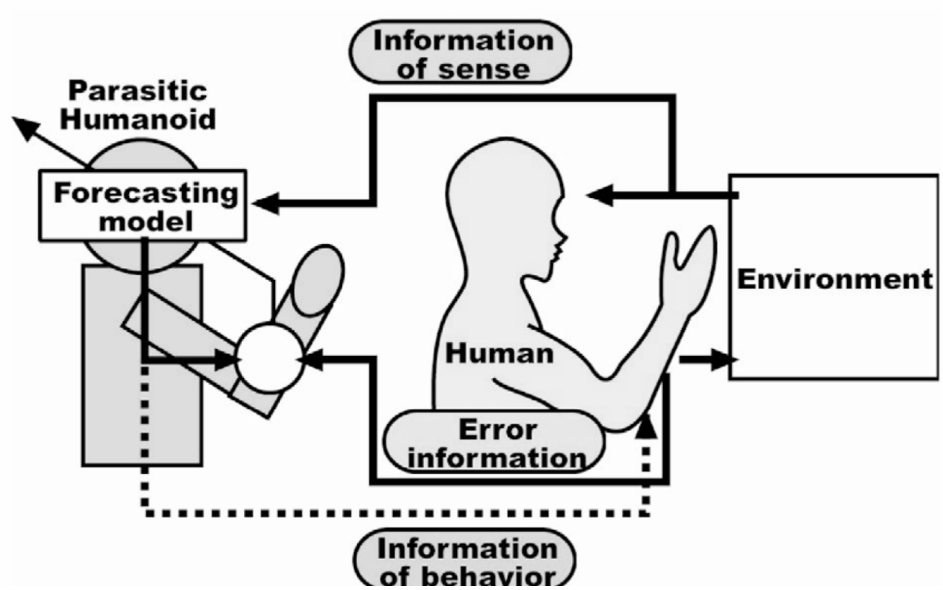

Figure 4.3: Showing the symbiotic relationship between the wearer and parasitic humanoid. [85]

Through its multiple incarnations and numerous applications, the *parasitic humanoid* remains a research platform for extensive studies. There are multiple

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[84] *Ibid.*
[85] Iizuka, Ando, and Maeda, op. cit. Anticipation of Human Behavior Using "Parasitic Humanoid". 2009.

parasitic humanoid research streams that have various application scenarios for situated prediction of wearers' non-verbal behavior.[86] The *parasitic humanoid* is an interface for "capturing and retrieving behavior"[87] capabilities that are useful in scenarios where learning via effector induction of feedback derived from personal-best or expert-modeled actions benefits from being in Maeda's words "free from verbal information that is distracting for continuous behaviors."[88] In 2010 Maeda et al. began publishing research about remotely guided first aid via a variant of the *parasitic humanoid*. As they describe it:

> [Parasitic humanoids are] wearable robots for modeling human movements. These robots can sense eye movements, finger touching, posture, and locomotion. They use an internal computer to process these sensor data, allowing continuous learning of the user's sensorimotor patterns. The purpose is to predict and 'optimize' human sensorimotor behavior.[89]

Parasitic-humanoid-based telehealth research includes a sub-area of "wearable behavior navigation system" investigations, which include remote guidance and augmented-reality (AR) subsystems that are simplified parasitic humanoid systems with minimal modeling and prediction capabilities. Combined bi-directional audio, visual, touch, and muscle stimulation signals are shared between the remote supervisor and local "cooperator" wearing the *parasitic-humanoid.* This sensorial feedback enables "experts" to remotely induce voluntary and involuntary movements of cooperators present with, and giving first aid to, a patient. Tightly integrated and fluidly co-coordinated visual overlay of expert and cooperators first-person perspectives is

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86 *Ibid.* P292
87 Maeda, Taro; Ando, Hideyuki; Sugimoto, Maki; Watanabe, Junji. Wearable Robotics as a Behavioral Interface -The Study of the Parasitic Humanoid. IEEE Proceedings of the 6th International Symposium on Wearable Computers (ISWC'02). 2002. P2
88 *Ibid. P*3
89 *Ibid.* P1

conducted as a mutual emulation which *parasitic-humanoid* researcher term as isopraxis.[90]

Figure 4.4 Diagram shows an early prototype of parasitic humanoid.[91]

While the *parasitic-humanoid*-based experiments conducted entail tight coupling of technologies and humans, the *parasitic-humanoid* introduces significant visual and perceptual distortions. As the developers of the system acknowledge, perceptual misrepresentations included reduced depth perception, “distorted correspondence between the displayed view and the real view,” and the head-mounted, augmented reality display narrowed the cooperator’s field of view.[92] Significant technical hurdles remained for composite bidirectional multisensory feedback. The *parasitic humanoid’s* current state is inadequately interoperable, ergonomic, personalized, or robust for field deployment.

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[90] Haraway, Donna J.. The Companion Species Manifesto: Dogs, People, and Significant Otherness. Chicago. Prickly Paradigm Press. 2003. P229
[91] Maeda, Ando, Sugimoto, Watanabe*, op. cit.* Wearable Robotics as a Behavioral Interface. 2002. P4
[92] Oyama *et al, op. cit.* A Study on Wearable Behavior Navigation System - Development of Simple Parasitic Humanoid System. 2010. P5321

My reading of the research on *parasitic humanoid* telehealth suggests that it demonstrates the weak adaptivity of centralized wearable robotics architectures. The significance of *parasitic humanoid*-based research findings is that it indicates that unreliable technologies frequently and significantly degrade the quality of the telepresence experience. Only some technical shortcomings of the *parasitic humanoid* can be rectified by incrementally increasing the number and types of sensor effector couplings, concomitant on-board integration, situational modeling, and prediction improvements.[93] These shortcomings are in part surmountable by human proficiencies for visual performance and understanding.

The *parasitic humanoid* demonstrates how human-based computation is an indispensable buffer ensuring robust contemporary technologies.[lvii]

> The concept of the design on Parasitic Humanoid is that the most valuable resource in wearable technology is the body of the wearer. The body is the structural frame work, the resource of sensory information, the display devices for perception, and the actuator for behavior simultaneously.[94]

The robustness and versatility of *parasitic humanoid* is precisely because it delegates to its human wearers what humans are best at, and focuses on the limited repertoire of better-than-human capabilities which contemporary technologies offer. In summary, the *parasitic humanoid* is a wearable robot which performs in the real world by reducing or excluding any physical and software capabilities resources that are not devoted to capturing, modeling, and predicting human behavior.

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[93] Oyama *et al, op. cit.* A Study on Wearable Behavior Navigation System - Development of Simple Parasitic Humanoid System. 2010. P5318

[94] Iizuka; Ando; Maeda*, op. cit.* Anticipation of Human Behavior Using "Parasitic Humanoid". 2009. P286

AudiSoft

The second competitor comes from the AudiSoft mobile video communication company headquartered in Québec. Audisoft develops and markets a commercial mobile telepresence system that is competitive with to my proposed WEHST system. AudiSoft's three primary product categories are server software for managing clients' servers[lviii]; proprietary video compression algorithms[lix]; and a proprietary suite of field equipment comprising high-definition body-mounted hands-free cameras, audio headsets, and wearable PC computers.[95] AudiSoft's tools are engineered to "integrate smoothly into any corporate infrastructure"[96] to enable rapid, expert, lean, human-resource-efficient, cost-effective operations during system-wide or localized problems. AudiSoft decentralizes hardware and software to strengthen remote administrators' technical capacities to equitably distribute resources in troubleshooting phases.

Figure 4.5 AudiSoft Frontline HD.[97]

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[95] Bassett, Renee Robbins. Streaming video into HMI/SCADA. April 2012, Automation World. Summit Media Group, Inc. Chicago, Illinois. P40
[96] *Ibid*. P40
[97] http://www.audisoft.net/Product/AudisoftCommunicationSolution.aspx

Figure 4.6 AudiSoft Frontline HD;[98] hard hat camera, ear muff camera, headset camera, handheld camera, frontline HD harness, and external battery charger.

While AudiSoft's telepresence product line is predominantly oriented at security, public safety, and heavy-industry markets, their telehealth capabilities give them a humanitarian veneer. AudiSoft's capabilities are demonstrated in case studies showing their value in applications spanning from wound care to humanitarian field hospitals in conflict zones. For example, the *Tele-Assistance en Soins de Plaiis* (TASP) network of 80 Canadian clinics was launched in 2010 to augment nursing care in rural communities with teleclinical resources specialized for wound care. *Tele-Assistance en Soins de Plaiis* telecare saves money, time and lives by supplementing community-based patient care with rapid and proactive access to specialists, whose skills are distributed widely without being spread thin.[99] [lx]

AudiSoft is an inception partner in Québec's *My Digital Primary Health Care* project aimed at improving provincial health and social care services by applying digital communication tools. These services, which include patient-to-specialists

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[98] http://www.audisoft.net/Product/AudisoftFrontlineHD.aspx
[99] AudiSoft Case Study. "Providing Wound Care Through Tele-assistance" Downloaded June 2014 from: http://www.audisoft.net/Documentation/tabid/117/articleType/ArticleView/articleId/43/An-Audisoft-Case-Study-TASP.aspx

videoconferencing, promote both patient-led proactive self-care and team-based interdisciplinary networks of professionals. While *My Digital Primary Health Care* is significant it is not ground-breaking telehealth research, as it does not utilize wearable capabilities. Spanning from April 2012 to March 31, 2015, this project applies experimentation in medical settings. Within this time-frame it took until March 25, 2014 to create a suitable research project which advanced *My Digital Primary Health Care's* three parallel streams of: privately (industry) funded research and technological development (R&TD)[100]; clinical research encompassing both patient and healthcare professionals; and concurrent evaluation by inter-university research teams. However, this clinical trial does not bring tele-care into the field, and at the end of the day only patients are mobile.[lxi]

AudiSoft also supports *Médecins sans Frontières* (MSF) tele-consulting and tele-proctoring[101] initiatives supporting pediatric care in a district hospital in Somalia. *Médecins sans Frontières* applies AudiSoft software to managing latency and bandwidth challenges exacerbated by the cost and danger of physically bringing specialists into the hospital. Considerable improvements in pediatric-care management using tele-care changed how half of cases were managed, detected initially undiagnosed life-threatening conditions in one quarter of cases, and reduced adverse outcomes ("deaths and lost to follow-up") by 30% (from 7.6%).[102] However, the system

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[100] Documentation regarding AudiSoft as an inception partner of the "My Digital Primary Health Care" project downloaded May 2014 from: http://www.mapremierelignenumerique.ca/en/project/; and http://www.cefrio.qc.ca/en/projects-research-investigations/Digital-technology-health/my-digital-primary-health-care/

[101] Tele-proctoring involves overseeing or supervising the education or work of remote personnel.

[102] Zachariah, R., Bienvenue, B., Ayada, L., Manzi, M., Maalim, A., Engy, E., Jemmy, J. P., Ibrahim Said, A., Hassan, A., Abdulrahaman, F., Abdulrahman, O., Bseiso, J., Amin, H., Michalski, D., Oberreit, J.,

does not have bidirectional video, high-resolution screens for consultation and training, or use any of the mobile AudiSoft field equipment for medical applications. While the Somali conflict zone does not entice clinicians to venture outside their remote district hospital, the highly centralized and stationary architecture of the AudiSoft software, as deployed by Médecins sans Frontières, disregards most aspects of clinicians and patients mobility or situatedness.

Future Soldiers

Figure 4.7 Left, France's Armée de Terre *FÉLIN* (Fantassin à Équipement et Liaisons Intégrés[103]; and right, US Army *Nett Warrior*.[104]

The third competitor comprises the category of "future soldier" (FS) programs ongoing in approximately twenty countries worldwide.[lxii] *En masse* future soldier programs seek to make soldiers more effective by developing modular approaches to integrated systems of all equipment. Modular systems are rapidly adjustable to suit individuals and teams across day, night, urban, jungle, desert, winter, alpine, naval,

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Draguez, B., Stokes, C., Reid, T. and Harries, A. D. . Practicing medicine without borders: tele-consultations and tele-mentoring for improving paediatric care in a conflict setting in Somalia?. Tropical Medicine & International Health. Volume 17, Issue 9, pages 1156–1162, September 2012

[103] Websites accessed June 2014: http://www.army-technology.com/projects/felin/; http://alliancegeostrategique.org/2012/06/05/neither-miracle-nor-catastrophe-for-the-first-2-0-french-soldiers-in-afghanistan/; and, http://www.senat.fr/rap/a12-150-8/a12-150-815.html#toc290

104 Websites accessed June 2014: http://www.army-technology.com/news/newsusarmy-installs-smartphone-nettwarrior-system; and http://asc.army.mil/web/tag/nett-warrior/

airborne, mounted, static, and foot-patrol missions. France and the USA have developed some of the few widely deployed systems. *France's Armée de Terre FÉLIN* system *(Fantassin à Équipement et Liaisons Intégrés)* and the USA's multiple *Future Force Warrior Program's* multiple iterations, of which the *Nett Warrior*, *Air Warrior*, and the *Mounted Soldier System* (aka *Ground Warrior*) are active.

Figure 4.8: Soldiers integrate *Nett Warrior* into their training.[105]

Common to French and American systems (other than focus on killing) is deploying on-the-body computing resources that are coupled with body-mounted radios to improve situational awareness in, and of, field operators. *FÉLIN* and all *Future Force Warrior* variants include basic telepresence capabilities via radio transmission of audio, video, and data. *FÉLIN* and the *Nett Warrior* variant are both combat-oriented wearable systems comprising modular sensing, computation, and control components mounted on hands, arms, torso, head, body armor, and their primary weapon.

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[105] Accessed December 2014 from: http://www.army.mil/media/270100

FÉLIN wearable systems demonstrate how contemporary technologies may augment communications, strategic, and defence (ballistic and chemical-biological-radiological-nuclear-explosive) abilities by integrating differentiated sub-systems. *FÉLIN's* architecture of discrete sub-systems allots: multiple radios, navigation system, wearable computer, software, headgear subsystem, armor, combat uniform subsystem, physiological status monitor subsystem, microclimate cooling system, and power subsystem. *FÉLIN* is chemical-biological-radiological-nuclear-explosive-ready (it includes an optional CBRNE mask and suit in its ensemble) and is widely deployed, from Afghanistan (2011) to Mali (2013).[lxiii]

FÉLIN and *Nett Warrior* are deployable as successive blocks of modular matériel, in order to ensure operators' safety first through graduated roll-outs adapted to contexts with different levels of command and requiring different configurations. The power, data, mechanical, and control architectures of these systems are highly centralized.[lxiv] Bi-directional telepresence by future-solider systems is delimited by the centrality of weapon and targeting systems in interfacing the solider and their wearable computer. In general, the primary future solider system telepresence inputs and outputs are integrated into their weapon systems and helmet-mounted heads-up display.

As a means of telepresence production, future-soldier systems embody a philosophical anthropology of humans inseparable from guns and armor, and beholden to hierarchical control.[lxv] This is ethically problematic, as effectively calibrating future-soldier systems to individual and group dynamics obliges intimate knowledge of underlying psychophysiological processes which presently require informed consent to disclose.[lxvi] In summary, future-solider systems may inadequately empower their operators to participate in those “horizontal” command structures that enable the human-based computation required to adequately conduct wearable telepresence using contemporary technologies.

4.3: Alternatives to my device

Those commercial devices, which are alternatives to my proposed WEHST device, are patient-oriented task-specific telehealth clinical instruments, portable and highly-integrated mobile telehealth products, and ad hoc mobile telepresence devices. These alternative devices also have in common their complementarity with my proposed teleparamedicine system.

The first group that I consider are patient-oriented task-specific telehealth clinical instruments for collecting and transmitting patient data during caregiving by frontline healthcare workers. These comprise ensembles of electronic telehealth diagnostic, monitoring, therapeutic and communication tools[lxvii] are often built on a foundation of proprietary videoconferencing software such as *Skype, Polycom, VSee, AudiSoft,* or *Cisco*. *VSee* is exemplary as a highly scalable and secure videoconferencing software application with low-bandwidth capabilities. *VSee* is a proven platform for telemedicine in clinical, disaster, and humanitarian response settings with use of *VSee* telemedicine kits.[106] The *VSee basic telemedicine kit* includes laptop tablet, electronic stethoscope, electronic otoscope, electronic iris scope, and a one year *VSee* telemedicine

[106] Accessed May 2014 from: http://vsee.com/telemedicine

subscription. The *VSee Advanced Telemedicine Kit* consists of the *VSee* basic telemedicine kit plus a portable ultrasound, portable EKG, and pulse oximeter.

Figure 4.9: Photomontage shows how *VSee Telemedicine Platform* integrates multiple telehealth clinical instruments.[107]

VSee explicitly avoids complex or specialized hardware or infrastructure in order to perform telemedicine without requiring expensive high-bandwidth networks. *VSee* has “one-click” Web-calling and remote screen sharing, high-definition (HD) video and remote three-axis (pan/tilt/zoom) servo-actuated camera control. *VSee* integrates combinations of suites of medical devices. *VSee*’s simultaneous and remote sharing of medical charts, treatment plans, medical device readings and patient-side high-definition video is transmitted over consumer networks and 3G cellular networks. *VSee* is fitted to infrastructure and budgets in rural, developing, and disaster areas. These make *VSee* more appropriate for portable and mobile applications by early adopters than competing platforms such as *Skype* or *Vidyo*. *VSee’s* connectivity and accessibility is offset by the general insecurity of transmitting and sharing patient records via telecommunication networks.[lxviii]

VSee is representative of a class of telehealth technologies immediately and widely adoptable by Canadian advanced telehealth clinics, as it is a system versatile

[107] *Ibid.*

enough to support both nurses or physicians tele-clinical care in areas of psychology, rehabilitation, psychiatry, emergency medicine, neurology, speech therapy, wound care, dermatology, ophthalmology, emergency rooms, intensive care units, or oncology. Furthermore, at its most mobile *VSee* is implementable as a low bandwidth satellite internet enabled *portable solar-powered telemedicine backpack* for disaster response.

VSee is a disruptive technology that ameliorates the disturbances it introduces by accommodating the needs of particular jurisdictions, specializations, institutions, patients, or environments. *VSee*'s configurability permits multiple types of focus while supporting front-line caregivers or administrative and support teams. *VSee* supports both centralized and decentralized approaches which respectively contrast a wheel-and-spoke model versus mobile, multimodal, *ad hoc* communication by dispersed teams of specialists. The centralized model is relatively closed, with prescribed command and communication roles across a unified block of infrastructure and human resources that enable serving economies of scale while generating unmanageable volumes of sensitive data.[108] Conversely, decentralized approaches reconcile diversity among stakeholders, support early adopters, reduce adoption costs, and extends medical care to patients outside existing programs.[lxix]

A second class of alternatives to my WEHST design are portable and highly-integrated telehealth products from companies such as *Librestream* or *LifeBot*. These are ideal for field clinics and ambulance-based telehealth. These telehealth tools enable remote care delivery while reducing the hazards and costs of deploying telehealth

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[108]"Tele-ICU comes of age" Accessed May 2014 from: http://www.healthcareitnews.com/news/tele-icu-comes-age?single-page=true

systems in both hospital-to-hospital and hospital-to-ambulance communications. Such handheld telehealth and videoconferencing devices (weighing up to 7 kg) do not account for paramedic safety or self-care in search and rescue and rescue or chemical-biological-radiological-nuclear-explosive settings, and are simply a class of portable data encoders with little computing power.

Figure 4.10: Handheld telepresence systems *LifeBot 5*[109] and *Librestream Onsight*.[110]

The final and most basic alternative to my system are the panoply of *ad hoc* mobile telepresence devices already widely used by paramedics. These off-the-shelf assemblages consist of combinations of generic cell phones, cameras, tablets, portable radios, or even *Google Glass*-type applications. These *ad hoc* assemblage type telehealth solutions exemplify the shortcomings common to the alternatives considered here. Each of these telehealth systems are, to varying degrees, low-fidelity, low-bandwidth, generally single-direction, non-secure, and often asynchronous. Each of these contemporary telehealth systems is inadequately flexible to offer anything more than loose couplings among their human operators or between operators and their technologies.

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[109] Accessed May 2014 from: http://www.lifebot.us/teletriage/; and http://www.lifebot.us/lifebot-one/
[110] Accessed May 2014 from: http://www.librestream.com/products/onsight-devices/onsight2500ex.html; http://www.librestream.com/products.html; and http://www.librestream.com/solutions/field-service.html

4.4: Designers

> If it is true as I have claimed that we have never been modern, and if it is true, as a consequence, that "matters of fact" have now clearly become "matters of concern", then there is logic to the following observation: the typically modernist divide between materiality on the one hand and design on the other is slowly being dissolved away. The more objects are turned into things – that is, the more matters of facts are turned into matters of concern – the more they are rendered into objects of design through and through.[111]

The designers who most inform my work are those researchers whose programs are guided by (research) design paradigms for explicitly creating objects in line with teleparamedicine's central dilemma of contending with and caring for an actants' embodiment. I concur with Latour's surmise that design practice is growing in comprehension and extension. I follow those designers[112] who break with industrial design's historical preoccupation with base material objects. Instead, the design paradigm I value treats embodiment as an ongoing and open-ended project that demands that we imbue "products" with attributes that understand how they are active – as they *are* actants – when introduced into a setting. Design for the interplay of technical, ergonomic, and environmental aspects of WEHST necessitates redefining teleparamedicine to actively seek to be closer to both paramedic and patient. While this section focusses on designers of research programs, and excludes industrial designers *per se*, my experience as a design researcher and practitioner leads me to understand the industrial design paradigm as tending towards making project stakeholders aware of the costs and benefits of decentralization as a control strategy.

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[112] Latour*, op. cit.* A Dialog on Actor Network Theory with a (Somewhat) Socratic Professor. 2004. P75

Teleparamedicine system-level self-organization capabilities balance centralized and decentralized control of teams and of technologies. To accomplish this obliges positioning industrial design to make fine-grained design decisions and attuning technologies to constraints of heterogeneity, unreliability, insecurity, latency, limited bandwidth, and dynamic topologies early on in the process.[lxx] Even further upstream are the need for design decisions informed by the profound policy and regulatory implications for system designs with multiple (uncoordinated, unskilled, and possibly unqualified) administrators and the building and maintenance of costly transmission capabilities.[113] Positioning design early (colloquially “upstream”) in the research and development cycle also embraces that community of designers who are prospective teammates and employers whose practice aims to reconcile the weaknesses and strengths of distributed computing. These researcher/designer/developer clients are those applying embodiment-oriented theories to working prototypes in robotics and artificial-intelligence fields. These designers understand human-centered design as flawed and biased.

Research, design, and development through embodiment-oriented approaches encompass the technological and human sides of human-computer interaction. WEHST aims to accomplish a minimal technical embodiment by simultaneously emulating, interfacing with, and delegating processes to paramedics’ bodies. Embodiment grounded approaches take actants’ behavior as bottom-up self-organization among

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[113] Peter Deutsch 1994. These shortcomings are enumerated in the list of Eight Fallacies of Distributed Computing. Downloaded January 2014 from http://java.sys-con.com/node/38665.

heterogeneous behaviors where cohesive organization of behavior is an observer effect.[114] [lxxi]

Disembodied approaches to understanding human cognition generate inadequately robust models of environmentally embedded and extended behavior. Work by Rodney Brooks and Mark Tilden exemplifies how an approach to robust real-world ready technologies might have profound implications for ontological considerations driving design, research and development of tools, practices, and policies.

Rodney Brooks is an Australian roboticist, scientist, author and entrepreneur[115] notable for advocating for the “actionist” approach to challenge computation as the central conceptual metaphor for the artificial intelligence discipline. Brooks’ 1980’s bottom-up redesign of artificial intelligence expressly excludes symbolic reasoning capabilities. This artificial intelligence is grounded in proprioception by, and coordination of, the sensor-motor system to interact competently with environments.

Giving bodies to artificial intelligence led to continuous and complementary advances in artificial intelligence and robotics. Brooks' action-oriented approach to lower-level perceptual and motor-skill integration is now known as “nouvelle AI.” Beginning low – at insect-level intelligence – nouvelle AI continues today to work toward humanoid artificial intelligence. This “behavior-based artificial intelligence” (BBAI) is grounded in modular decomposition of intelligence to successfully instantiate real-time dynamic systems operating in complex environments. Intelligence is an emergent property of cooperative control by a set of independent semi-autonomous modules.

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[114] Embodied Cognition. Shapiro, Lawrence A. Routledge, 2011. P141
[115] Biography of Rodney Brooks downloaded January 2014 from http://people.csail.mit.edu/brooks/

Whether separate devices or discrete processing threads, these modules, as hardware or software, were initially conceived as entirely reactive, with no learning or planning capabilities.

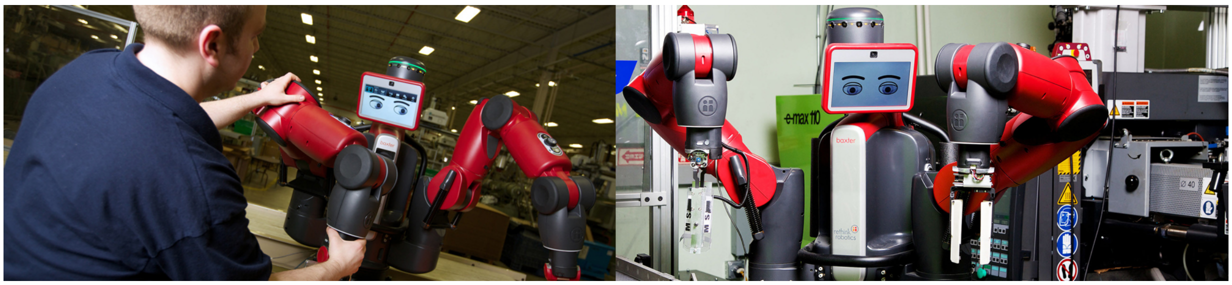

Figure 4.11 Rodney Brooks' mass-manufactured Baxter robot applies subsumption architecture and is used for light industrial manufacturing[116]

In its most extreme form nouvelle AI demonstrates the utility of situated approaches for real-world adept situated artificial intelligence. However, situated robotics and artificial intelligence include those software agents existing in dynamic environments, which they perceive and manipulate through actions that include agent-reflexive changes. Situated robotics brings attention to the embodiment of software, firmware, middleware, and hardware as distributed, decentralized and always *in becoming*. Inversely, situatedness emphasizes agents' interactions with their environment, whereby an agent's embodiment is defined by these interactions. Situatedness supports a radical perspective of agents becoming not just embodied and embedded but also reciprocally extended with their environment.

While being situated is part of being embodied, being embodied is equally – from more radical ecological perspectives – part of being situated among coordinating bodies. This radically situates robotics in environments which change through both the

[116] Accessed December 2014 from: http://www.rethinkrobotics.com/

actions of the agents they perceive and through changes wrought in their environment by their own activity. Multiple embodied agents may be assembled through subsumption architecture. As one commentator has written: "Brooks has designed his robots to instantiate and exploit the coupling between the world, the robot's perception of the world, and the robot's actions on the world." [117] Subverting traditional "sense-model-plan-act" architectures, Brooks' subsumption architecture[lxxii] sidesteps representationalist paradigms of "sense-model-plan-act," by bypassing modeling and planning, and directly coupling sensing with behavior.

Subsumption architecture, even in its strictest application, enacts bottom-up control architecture appropriate for fully autonomous and real-time applications in robotics and artificial intelligence. Subsumption architecture is also promoted as a model for human cognition – and continues to hold some ground against paradigms promoting symbolic mental representations of an external-world guiding behavior. Subsumption architecture decentralizes control through a hierarchy of activity-producing layers, each enacting a particular level of behavior. Coherent behaviors are decomposed into sub-behaviors allocated to particular sense-act layers, and the overall behavior emerges from higher layers subsuming lower layers by inhibiting or disregarding lower layers.[lxxiii]

> Each layer within the control system produces a particular behaviour in response to sensor activity, and because the layers have the power to inhibit or ignore each other, the overall behaviour that emerges from the combined layers is surprisingly coherent and versatile.[118]

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[117] Embodied Cognition. Shapiro, Lawrence A. Routledge, 2011. P139
[118] *Ibid.*

Mutual interplay of parallel layers of sensor-effector couplings occur in real-time and the number of layers may be increased or decreased by physically adding layers, or by dis-inhibiting suppressed layers. Shifting layer counts to match the dynamics of particular environments is via an integrated physical control system directly grounded in the real world by embodiment as discrete individual modules. The emergent behaviors of aggregate modules are too complex to credibly create and test as solely theoretical models.

However, the greatest influence of subsumption architectures is in the contrast of its strengths of iterative real-time testing, connecting task-specific sensing to required actions and distributed control among subsystems. This is offset against its weaknesses in developing the case-specific particular weighting of inhibition and suppression among parallel layers, and a lack of extensive memory, both of which are in part consequences of an absence of central control. These weaknesses may be recast as strengths, as advantages of the system's modularity permit introducing human operators as instances of human-based computation through wearable robotics. Human operators, incorporated as subsumption-architecture subsystems, give proven capabilities for learning complex actions. Humans have capacious memory for detailed mapping, are adroit with symbolic representations including natural language and paralanguage capabilities, and offer an appropriate locus for intermittent central control.

The phenomena underpinning the early successes of embodied and situated approaches to artificial intelligence and robotics are best explained by “Moravec's paradox” (see Appendix 10.2 about Moravec's Paradox and refer to Appendix 10.3 which covers Pentti Haikonen's embodiment-oriented approach to artificial consciousness). This paradox describes how high-level reasoning requires very limited computation resources – in contrast with low-level sensorimotor skills demanding vast computational resources. Moravec elucidated how we underestimate the complexity of processes we perform easily, which have evolved through natural selection over billions of years, and of which we are mostly “unconscious”.[lxxiv]

When technology fails to cooperate in efforts to reduce it though rational principles, human embodiment offers not just a paradigm but a material substrate of highly refined, yet poorly defined intelligence. Human embodiment is a basis for leveraging new technologies for use in complex settings, particularly in light of the role of embodiment in human-based computation. Extending human to technology symbioses is through processes of reciprocal top-down and bottom-up control with their ecosystem.

UK-born, Canadian-raised, Hong Kong-based Mark Tilden is a robotics physicist who works as designer, entrepreneur, and public advocate for his invention: *BEAM robotics*. *BEAM* is a robotics approach using generally a “low-level hardware-centric design philosophy” inspired by Rodney Brooks’ “reaction-based” robotics behaviors. Tilden’s *BEAM* robotics approach endows sophisticated stimulus-response-based abilities to simple robots simulating biological neuron behavior. *BEAM* uses simple analog circuits, instead of microprocessors, as a “nervous network” of simple electrical neural networks using biomorphic techniques to mimic physiological neuron behaviors as the control layer for autonomous mobile robots. *BEAM* applies the minimum possible set of electrical elements and an overall strategy of efficient and robust designs sacrificing some flexibility in order to succeed at the task.

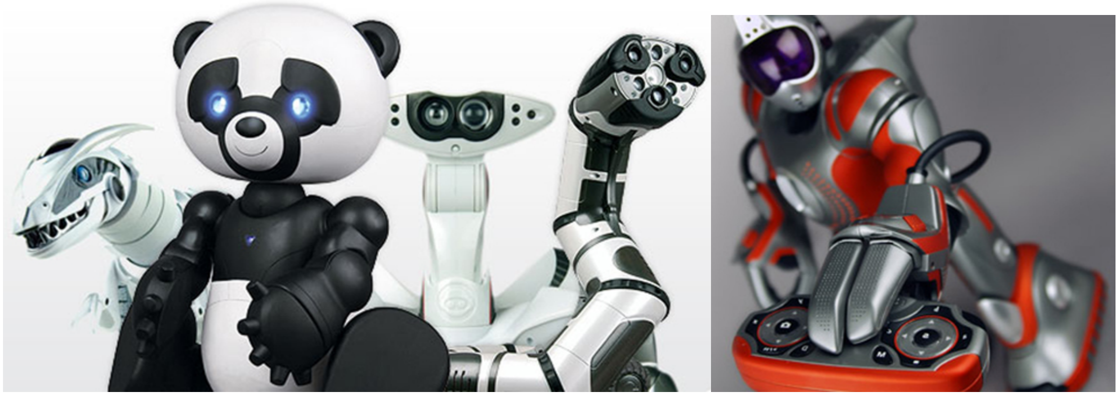

Figure 4.12: Mark Tilden works with Wowee Group Limited, an independent research and development and manufacturing company founded in 1988. Wowee applies BEAM robotics architectures in designing, developing, marketing and distributing consumer robotic and entertainment products. [119]

Among competing explanations for the *BEAM* acronym, the most widely accepted explanation is for Biology, Electronics, Aesthetics, and Mechanics as the basis of *BEAM's* acronym. The *BEAM* robotics community of roboticists, researchers, and hobbyists align themselves with Tilden's life work of "microprocessorless" robots with complex movements and behaviors produced via biologically inspired analog electronic circuits. These fit productive applications for physiological coupling through biological mimicry for human-based computation. These principles have been applied to an extensive line of commercial biomorphic robot products from *WOWEE Toys.* These toys have been a significant cultural and commercial influence since 2000. Dozens of *WOWEE* robots and related toys continue to extend the already significant influence of Tilden's early research at University of Waterloo and Los Alamos National Laboratory.

[119] Image downloaded July 2014 from http://wowwee.com/en/products/toys/robots/robotics/robocreatures; and http://www.wowwee.com/en/products/toys/robots/robotics/robosapiens/rs-media

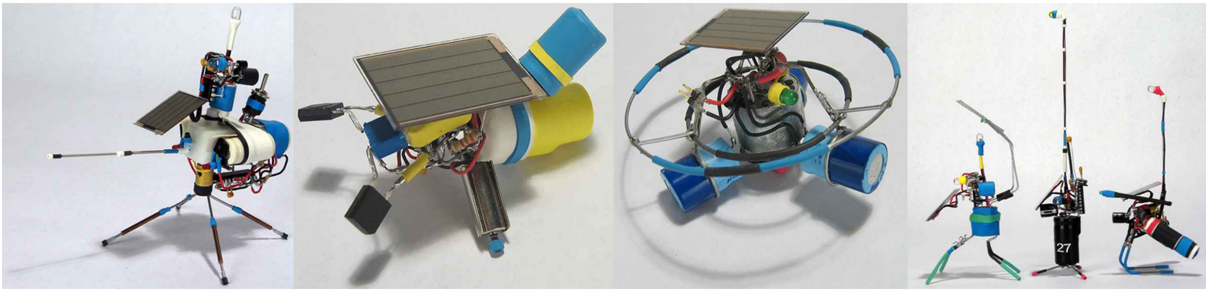

Figure 4.13: A small sample of BEAM robots representing the "Head", "Popper", 'Symet", and "Pummer" architectures.[120]

The wider community of *BEAM* roboticists, makers, and hackers modify the multitude of commercial-entertainment robots Tilden has designed. This community builds *BEAM* robots from (largely generic) parts, plans, and kits available from commercial and community resources, and contribute new and innovative concepts to the wider *BEAM* community. The *BEAM* community of practitioners, in parallel with commercial products, have created conditions for *BEAM* robotics becoming a proto-science contributing to the wider project of behavior-based analog robotics excluding analog circuitry. *BEAM* robots lack internal models of their environment and pursue simple goals. This instance of hardwired intelligence not only bypasses programmers' microprocessors to achieve emergent behaviors of complex patterns from simple constituent motors, sensors, and artificial neurons, but exhibits seemingly intelligent actions in context.

Tilden has enumerated three guiding principles for beam robotics: "A robot must protect its existence at all costs. A robot must obtain and maintain access to its own power source. A robot must continually search for better power sources." The significance for wearable robotics posed by these principles is their approximate

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[120] Images downloaded September 15, 2014 from http://www.beam-wiki.org

correspondence with biological behaviors. *BEAM* is amenable to the inclusion of the human body as a discreet analog sub-assembly of its overall assemblage. It also makes a body-oriented *BEAM* specification possible as an analog co-constituent of a human body in motion and situated in a complex environment. *BEAM* can be specified to fit the human body, and at palm-sized most current *BEAM* designs are sized at an appropriately human wearable scale. BEAM construction techniques are simple, apply a wide range of tactile sensing designs, and suit wearability. Furthermore, the *BEAM* principle of developing complex behaviors by simple inhibitory and excitatory for links to the human body as the actuator. In keeping with the *BEAM* ethos these sensor systems would require little signal conditioning when linking directly to human body taken as effector of multitude simple behaviors.

Tilden's three principles for *BEAM* robotics offer loose guidelines for ANT black-boxing a human paramedic with a wearable *BEAM* robot in a particular task relating to teleparamedicine practices. This is comparable with those instances where *BEAM* injunctions against including (programmable) microcontrollers are overlooked and *BEAM*-hybrids are built to include digital computing capabilities. These human-*BEAM* hybrids are relevant both as prototype tools for wearable applications and as models for how *BEAM's* embodiment offers flexibility equivalent to microprocessors' dynamic programming. For instance, a largely autonomous *BEAM* robot's robust control system may benefit considerably from a human periodically subsuming the robot to overcome its deficiencies in sensing, acting on the world, or learning from past behavior. *BEAM* robotics may be applicable to wearable computational textiles as internalized subsystems of discreet WEHST modules or integrated with sensor/effector peripherals.

Hypothetically, a wearable *BEAM* would be instantiated predominately as hybrid subsystems of hybrids of microcontrollers and computer programming in tandem with biometric stimulus-response circuit-based analog robots coupling these two techniques. This is analogous to a horse-and-rider isopraxis topology whereby the microcontroller exercises only intermittent control over the functionally autonomous physical robot body. I appropriate the term isopraxis from work by both the *parasitic humanoid* team of Maeda et al and from Haraway's adaptation of French ethologist Jean-Claude Barrey's use of the term isopraxis to describe the phenomenon of mutual – and unintentional – physiological attunement between skilled riders and horses. [121] Isopraxis topologies are echoed at multiple scales of human-mediated teleparamedicine practices for coupling representational digital technologies with embodied analog skills to form distributed and decentralized systems of reciprocal subsumption and control.

To conclude this discussion of those designers most influencing my work I must also acknowledge the profound influence of the wider community of the British Columbia Ambulance Service (BCAS). This community of caregivers created the Infant Transport Team (ITT), and became exemplars of paramedicine in Canada and internationally. In contrast with the rigid and inflexible protocol-based paramedicine that is (almost exclusively) practiced worldwide, Canadian guideline-based paramedicine emerged through creation of the British Columbian Infant Transport Team in the 1970's. The Infant Transport Team is among the global leaders in using generic mobile telecommunications to continuously innovate in guideline-based paramedicine development. Infant Transport Team wearability requirements merit close study, as their

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[121] Haraway, *op. cit.* The Companion Species Manifesto. P229

guideline-based practices continuously refine semi-autonomous and context-specific decision-making processes. Guideline-based care sidesteps protocol-based care's rigid chains of command and resistance to improvisation or innovation. Infant Transport Team paramedics conduct assessments, administer drugs and perform procedures outside their official scopes of practice yet within their individual capabilities.

In conclusion, guideline-based paramedicine has two central paradoxes: surveillance by remote pediatricians facilitates paramedic autonomy; and paramedic autonomy leads to better-managed patient care. While contemporary guideline-based paramedicine toolsets are mobile and not wearable *per se*, Infant Transport Team practice illustrates the juxtaposition of surveillance and autonomy that my project promotes through teleparamedicine. These two paradoxes of guideline-based paramedicine both translate into instances of isopraxis whereby: the mutual attunement of paramedic and remote specialist enhance both the degree of specialist surveillance *and* paramedic autonomy; and, the mutual attunement between patient paramedic is the basis for enhanced paramedic autonomy leading to better-managed patient care. The horse-and-rider topology of isopraxis, whether it be paramedic-and-supervisor, paramedic-and-patient, or paramedic-and-WEHST are based on the exercise of only intermittent or partial control over functionally autonomous physical bodies.

Chapter Five: Paramedic Voices and the Design of WEHST

Figure 5.1: *Kootenay Heli-Rescue Society* training maneuvers with *Dam Helicopters*[122]

5.1 Why I chose my participants

This chapter describes what I learned from interviews with first responders (with a particular focus on paramedics). I first describe why I chose my participants (see Appendix 10.4 for a sample consent form); second, I review the advice and the observations integrated into my project; and third, I examine how these interviews influenced the design of the WEHST "assemblage". From among the many participants in my research I choose to privilege the voices of the first-response community – particularly first-response field operators and their attendant managers. As a group they have an intimate understanding of the problems and solutions underpinning wearable teleparamedicine technologies in emergency-response contexts.

Concern with first-responder's perspectives means attending to how these professionals who risk on a daily basis their own lives – and their families' well-being – to care for the general public. Paramedics shared experiences with, and speculations

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[122] Downloaded November 2014 from: http://kootenayhelirescue.com/ ; and http://www.damhelicopters.com/dam/

on, how to situate wearable teleparamedicine systems in complex relationships among patients, personnel, matériel, procedures, and environments.

The individual interviewees who contributed the most to my research also had the most to gain from its hypothetical deployment. Preeminent among this cohort were *British Columbia Ambulance Service Infant Transport Team* paramedic Ross Halloway, Sgt. Ron Condly (retired), *British Columbia Ambulance Service* paramedic Sharon Pol, Dr. Mike Inniss, Dr. Jeff Plant, pilot Dunc Wassick, and emergency managers Al Craft, Rene Bernklau, and Ian Cunnings.

Ross Halloway is a paramedic with approximately 40 years of experience – most of which was spent caring for infants. He is presently unit chief for *BC Ambulance Service Infant Transport Team*. Ross Halloway has experienced the full historical and political span of *Infant Transport Team* emerging as a community of practice through processes of shifting infant-oriented paramedicine from rigid medical protocols towards more flexible guideline-based care. Ross Halloway describes how the emergence of guideline-based care directly correlates with improvements in telehealth capabilities during transport of pregnant women, infants, new mothers, children and families.

All of my extensive contact with Ross Halloway (and his ITT colleagues) occurred in field settings where the almost constant presence of patients and the constant background radio chatter made recorded interviews incompatible with maintaining the privacy or consent of patients or other paramedics. While no recordings of Ross Halloway or other *Infant Transport Team* paramedics were made, as a community the *Infant Transport Team* made the greatest single contribution to situating my research.

I also chose to include the voice of Sgt. Ron Condly. He is a recently retired search and rescue technician (SAR Tech) and former *Joint Rescue Coordination Centre* staff member (Victoria, B.C.). As a 20-plus year veteran of the *Canadian Air Force*, Sgt. Ron Condly is the only person to twice complete the mercilessly rigorous 14-month search and rescue technician (SAR Tech) training program. More than most, Sgt. Ron Condly understands the absolute physical and cognitive limits of paramedicine. Since 2006, Sgt. Ron Condly has been a key informant regarding how telehealth may augment training and teamwork to overcome those paramedicine situations, which inevitably lead to communication breakdowns among humans and technologies.

> I've had about four or five instances in where I had to relay my patient's conditions through the pilot. The pilot is a highly, highly trained individual. Very skilled, very critical part of our team – but is not medically trained. I am bound by relaying through that person my hospital report, which is mobilizing resources – and in some cases I'm asking for information. (Sgt. Ron Condly, May 20, 2012)

Sgt. Ron Condly understands how paramedics transporting acutely ill patients need to clearly communicate with remote "resource physicians" and "receiving physicians" (who they may also meet face-to-face). For example, Sgt. Ron Condly is familiar with the nuances of getting detailed diagnostic information from a physician via indirect communication from a remote site. For example, when a paramedic is transmitting medical information via remote non-medically trained personnel key words may be missed; medical terms may be mistranslated (by a pilot or similar non-medical professional) into non-medical lexicon; and these misinterpretations may be transmitted forward to the remote physician (who then has to consider if the paramedic with the patient is competent).

I also chose to include Sharon Pol's account because she is both a level 1 *British Columbia Ambulance Service* paramedic and is a certified helicopter rope-rescue technician who is a volunteer member of the *Nelson Search and Rescue* initial response team. As a paramedic *and* female search and rescue operator her extensive skills and unique experiences provide a perspective indispensable to understanding how to deploy novel team-based telepresence technologies in the field. Sharon Pol's experiences speak to the possibilities for – and value of – teleparamedicine bringing more women into front-line roles both physically and virtually. As a female paramedic who became certified as a helicopter external transport system (HETS) operator Sharon Pol has profound insight into the mindset of the predominantly male search and rescue community.

Her extensive involvement as a professional and volunteer in the first-responder community also enabled Sharon Pol to describe the nuances of paramedics' complex experiences in plain language:

> You're given guidelines; you know your triage levels. You've got your partner to bounce the information off of. You fall back your training. It's hard, but you've got to be solid in your training. Training in mass casualty is a huge one. You want to go with your heart… versus your head that tells you to save the savable. […] It's a tough environment to be in. I've done a couple of mass casualty, and it's difficult. The volume of information that comes flooding at you – the bombardment of all of your senses – it's phenomenal. It's like anything – the more you do the easier it gets – or I shouldn't say easier – but the less difficult it gets when falling back on that solid training. (Sharon Pol, July 25, 2012)

Sharon Pol described how paramedic or search and rescue operator training isn't always adequate. Paramedics work close to their physical, emotional, and intellectual limits. Search and rescue operators spell each other off so no one person has to carry the brunt of a situation. Sharon Pol describes how in mass casualty incidents, "You go on a kind of autopilot where you know there is a job to be done and you just do it. The steps seem to come almost naturally. Things fall in line." This is in contrast with, how, where, and when paramedics stumble because they don't have the previous training or pre-information to make the decisions on scene. Sharon Pol uses the example of mass-casualty incidents to describe how first-responder performance is pushed to the boundaries of human endurance.

> The adrenalin is pumping. That superhuman guy lifts the car off the two year-old. It's almost out-of-body, almost surreal – because it's such a way-out-there environment to be in that how your body reacts in a situation is like nothing else. You don't have the time when you're doing the mass casualty incident to look at yourself and go "What's going on here?" But you do after the fact recognize how phenomenal your actions were in the situation. (Sharon Pol, July 25, 2012)

Sharon Pol describes how paramedics support each other on the ground. Teammates keep each other from going beyond their limits even if they are already performing incredibly well. She describes how paramedics may sometimes only see what is directly in front of them. For example, individual paramedics may become focused on a heroic yet only *possibly* life-saving resuscitation, and may need reminders to re-triage and shift care to less gravely ill patients nearby. These are instances where teleparamedicine collaboration benefits patients by focusing on paramedics. As Sharon Pol puts it,

> When you have those other people in your team about you, the team has the ability to help people who might be struggling - to guide them into a better path – a better outcome. (Sharon Pol, July 25, 2012)

In other words, what Sharon Pol emphasizes is how an individual paramedic always works in tandem, in synch with others. The overarching issue is of the need for coordinated actions beyond one individual.

Dr. Mike Inniss is a physician and wilderness trauma specialist in Nelson, British Columbia. Dr. Mike Inniss is also a *Nelson Search and Rescue Initial Response Team* member holding dual roles as helicopter rope-rescue technician and leader of *Organized Avalanche Response Team*. Dr. Mike Inniss is one of the few non-military Canadian physicians trained in rope-rescue. Dr. Mike Inniss has unique insight into the practical, technical, legal, ethical, and political requirements of (and ramifications for) using telehealth to convey specialist perspectives in *both* directions between expert hospital care and the experts in the field.

> Basically I generally feel it a rare exception a well-trained paramedic is not completely my equal. There's rarely a setting where I'd say [paramedic A] or [paramedic B] wouldn't do the exact same thing I did. There might be a situation where I might be more willing to relocate a dislocation or a fracture that was impeding circulation or something, I might make a call as to where we go, I might make the death call sooner – and feel a bit more comfortable, but it's rare. I know a top notch paramedic is in many ways much more qualified in this field than we are. We've been brought up in universities and trauma settings where we've got 12 people helping us in the room. A paramedic is much more skilled at assessing scene safety; detecting priorities, stabilization… triage is key, critical. Paramedics are well trained in triage. They know when something is hopeless. And then they know where not to divert all their energy. Physicians are generally poor at that in many ways. So triage is an important skill in SAR, and paramedics generally have that skill. It's something I've had to learn over time. (Dr. Mike Inniss, August 5, 2008)

Triage is contingent on the embodied knowledge of the paramedic. However accessing and operationalizing this knowledge requires the paramedic to retain the degree of autonomy they require to make triage decisions – even when remote teleparamedical supervisors are augmenting these triage processes in real-time.

Dr. Mike Inniss reports that the differences between physicians and paramedics during search and rescue operations are subtle. The more advanced medical training of physicians, when compared to a civilian paramedic or military search and rescue technicians (SAR Tech's), does not translate into added patient-contact time.

Physicians' extra skills in communication, assessment, decision-making, or procedures are minimally utilized. This is because search and rescue teams spend most of their time getting to accident scenes and carrying stretchers. This means telehealth by remote physicians supporting paramedics in the field fills a finite demand for patient contact.

> Probably I spend a bit more time as a paramedic than as a physician – which is basic stabilization, assessment, and triage. Probably 80% of the time is as one of the team of SAR, whether it's traveling to the site, helping with the evacuation, cleaning up afterwards. (Dr. Mike Inniss, August 5, 2008)

Dr. Mike Inniss tacitly understands that the differences between physicians and paramedics are complimentary dissimilarity of both type and degree. The specialized knowledge of the paramedic is mobile, in contrast with that of the much more extensive yet practically stationary physicians.

Dunc Wassick is a helicopter rescue pilot and base manager for *Dam Helicopters* and a rescue pilot for the *Kootenay Heli Rescue Society* (Nelson, BC). Dunc Wassick is a certified mountain-rescue pilot with over 12,000 hours of mountain flying experience, and maintains a Class-D certification for human external transport systems (HETS). This positions Dunc Wassick as one of Canada's most experienced and versatile search and rescue pilots. His vantage point, at the top of the rescue rope, gives Dunc Wassick unique insights into the costs, risks, and benefits of teleparamedicine in highly hazardous helicopter operations.[lxxv] Dunc Wassick has a birds-eye view, which succinctly frames how decisions unfold in real-time on the ground, on the rope, and in the cockpit. Search and rescue has two stages: first, searching for sign of somebody who is missing; and second, making decisions once they are located about how to extract the person.[lxxvi] For Dunc Wassick, rescue weighs whole-team options such as, "Which would take the most time? How critical is the patient? Can they walk to the site? Do you have to drag them through the bush?" His answers demonstrate how teleparamedicine's core value is in its ability to rapidly bring specialized care into the field without risking their lives or limbs.

> Basically the longline rescue is a matter of minutes to get someone out where it would take you hours to get off the hill by foot. It's that quick. Exposure for your people working with you and the patient is pretty minimal. It may be too hazardous to do that because of wind, and conditions, and visibility, and weather – and then yes, they come out the old-fashioned way - which is on a bobsled – or whatever they have there - a stretcher and that. It's more work. (Dunc Wassick, July 26, 2012)

Dunc Wassick illustrates how paramedical telepresence in – and out – is not just a matter of how far – but also of how fast – distances are bridged.

The perspectives of first-response managers, such as Al Craft, add long-term perspectives on the changes to, status of, and capacity for change by both rescue personnel and material. People and equipment together are a basis for estimating the need for coordinated timeliness in order to fulfill teleparamedicine's core value or bringing specialized care to the field. Al Craft is an emergency manager for the *Kootenay Heli Rescue Society*, director and crew chief of the *Beasley Fire Department* and *Beasley Rescue Society*, and a *Nelson Search and Rescue* initial-response-team member. Al Craft is also a paramedic with swift-water rescue technician and rope-rescue technician credentials. While approaching 60-years old, Al Craft remains very active in the field and has considerable insight into the value of a teleparamedicine as a possible means of managing individual first-responders' psychophysiological stress within heterogeneous emergency response teams.[lxxvii]

Al Craft is able to discuss how adopting remote telehealth supervision in order to perform increasingly advanced protocols for drugs and procedures, is not simply justified by improved patient outcomes. He contextualizes teleparamedicine adoption in an organizational perspective outlining multiple concerns. First, most advanced care is only possible if protocols are redesigned to make specialized drugs or instruments present in the field. Second, matching the personnel's level of training to level of equipment is ongoing. Third, communication is restructured to maintain contact with higher-trained supervisors. Fourth, softening the uproar from the medical field would require upgrading in the medical abilities of the person on the ground and in the hospital.

Al Craft's interview reinforces how embedded research capabilities enable ongoing clinical and field trials in telehealth settings – prior to, and throughout adoption of teleparamedicine platforms and practices.

> Again, having our own physician on board, who isn't there all the time, he's often gone way beyond what we could ever do. He carries his own drugs and things that have immensely helped patients' recovery out in the field. We're fortunate that way. There would be a lot who wouldn't want to go that far. They don't want to be doctors. It wouldn't be everybody's destiny to try and do something like that. They're happy at the level they're doing – or maybe a little bit more. There would be such an uproar from the whole community – whether it paramedics or the doctors end of it. Because it's a whole new area, they're going to study it to death before they approve something like that. (Al Craft, July 23, 2012)

Al Craft's long-term perspective shows how embedded research capabilities are legal and ethical obligations and include capacities for tracking both rescue personnel and material.

Rene Bernklau is the British Columbia provincial coordinator for hazardous substance response, a chemical-biological-radiological-nuclear-explosive (CBRNE) team leader at *British Columbia Ambulance Service*, and president of the *Association of Canadian CBRNE Technicians* (ACCT). Rene Bernklau shared his understanding of how telehealth material in contemporary and prospective hazardous environments may offset many of the obstacles to care-giving and communication posed by paramedic-worn personal protective equipment.

> Within the fire department they're working so hard to get that first guy in the Level A Suit videoing something back – so that we can start seeing what they're looking at. Because a lot of our hazmat operators are terrible descriptors –they can't tell us what they're looking at. They are also in a fog the whole time. So what might see is two cars – one is black one is white – but really there's a sidewalk and a few other things that they need to see for just taking a step. I would like to see a remote camera on the outside of a Level A Suit. However, you might not be in an environment where you get a focus. The sprinklers could be going off, there's grey, white, black smoke. (Rene Bernklau, August 30, 2012)

Rene Bernklau's familiarity with hazardous rescue environments enables him to speculate on possible requirements for possible combinations of hybrid manual, remote, and automatic control for camera, lighting, microphone, speaker, headset, and visual display components of telepresence production.[lxxviii]

Rene Bernklau describes the immediate value of adopting teleparamedicine as a means to simultaneously improve situational awareness and response time,

> Every time you've got two [responders] in you've got to have two [waiting] on the *Rapid Intervention Team* (RIT). So then they'll step in and they'll take over. You'll be flowing your people through, but what kind of job you get done in 20-30 minutes? You might get a good 'recce' [reconnaissance] in, and you can't start treating anybody, you really have a hard time treating in a Level A Suit. That is how every response starts out. You've got about an hour of Level A Suit until someone determines what the issue is. Then you might see the downgrade [to more agile and less stress inducing suits]. We've got to learn to do that faster in the field. (Rene Bernklau, August 30, 2012)

Paramedic-worn personal protective equipment offers a limited scope of view and window of time to individuals in hazardous environments. Telepresence needs to connect paramedics to: both immediate and remote teammates *and* their environments – for both care-giving and communication.

Ian Cunnings was chosen to contribute because of his experience as the search and rescue specialist at Emergency Management BC, the regional manager at *Emergency Management British Columbia*, and the regional manager of the provincial emergency program. Ian Cunnings describes the technical, ethical, legal, policy, and economic aspects of deploying prospective teleparamedicine technologies at municipal, regional, provincial, national, and international scales.

Ian Cunnings addresses how requirements for training standardization and maintaining documentation translate into ethological research capabilities. Ian Cunnings reports that a significant challenge facing ground search and rescue (GSAR) teams in British Columbia is training standardization. For example, it is important to identify and set the standards that crews teach to, in order for the North-Shore Search and Rescue and Nelson Search and Rescue have the same skill set. Ian Cunnings speculates that teleparamedicine could improve training and assessment and lead to greater interchangeability within, and interoperability among, first-response organizations.

Ian Cunnings also emphasizes the potential value of teleparamedicine in getting responders to take their own fitness levels seriously across trades, between individuals, and throughout careers.

> The other thing we're struggling with is where in the paramedic world, firefighters, police, when they start in that organization there is a level of fitness that's required within that.

> Now in the SAR [search and rescue] worlds there isn't. But does that help or hinder? Hard to tell, because we haven't had – or at least known to us – someone drop of a heart problem on a trail. Then you talk to police, fire, and ambulance – while there's a strict physical fitness requirement where they get on – but then it stops there. There is no ongoing [fitness tracking]. You get all different body types throughout the career of a first responder. (Ian Cunnings, August 30, 2012)

Perhaps future studies could observe experienced emergency managers to asses and address how introducing a teleparamedicine technology would have to be concerned with paramedic "fitness" programs at local, regional, and national levels. Fitness encompasses communication, physiological, and environmental considerations.

Each of these participants articulates the complexities of the experiences of working within the field of paramedicine. Their viewpoints on what it means to work within this field contributed directly to the design of WEHST, identifying a system of relationships among patients, personnel, material, procedures, and environments.

5.2 Advice and observations retained for project

The advice and observations retained for the WEHST design project were in large part selected based on whether they are useful, novel, and not-obviousness. Novel ideas do not infringe on others' intellectual property. Useful advice generally improves or establishes manufacturability, cost-efficiency, and usability of contemporary processes and materials. Non-obvious ideas do not have to be patentable as long as they are original – such as trade-secrets. These criteria overlap to some degree, and are limited to concerns regarding the originality of the proposed technology within an implicitly capitalistic framework reliant on "individual" property rights – incongruent with the ontological underpinnings of the WEHST platform. Such reductive criteria do not explicitly address global concerns for the integrity or sustainability of human and ecological systems. Usefulness, 'novelty', and non-obviousness are criteria that are appropriate for resolving technical dilemmas such as how material and process selection may balance manufacturability versus cost-efficiency.

This teleparamedicine design project is concerned with the emergence of hybrid human, technical, and ecological actors whose embodiments are appropriately complex and processual to preclude prescribing firm boundaries on their prospective worldviews. Thus, advice and observations are retained if they address concerns for stabilizing a wearable teleparamedicine system, which is comprised of non-local and non-unitary actor's at all possible levels. To narrow this down, I retained advice and observations roughly delineated by relevance to specific design of WEHST-based teleparamedicine first, and followed by the WEHST module families of COMmand, PSYchophysiology, POSition, and MEDia.

WEHST-based teleparamedicine is a practice of being in two places at once. While teleparamedicine grants access to hospital resources, materials, or relationships, its practicability includes practical, financial, and physical limitations of how much equipment is in the field. All research participants demanded a tightly constrained envelope for teleparamedicine devices in terms of size, weight, and attention burden.[lxxix] For example, Dr. Mike Inniss' ranks the importance of "kit triage" (on-the-fly selection of portable equipment) above patient triage, and emphasizes how this case-by-case winnowing of gear may severely curtail a paramedic's ability to treat a particular patient effectively.

> So that's one of the conundrums you find yourself in with a very unwell or injured patient: you often wish you had more equipment or were somewhere else. It's happened to me several times where I would say 'I wish I had this person with me' or 'I wish I had this

> equipment.' But then the art of SAR [search and rescue], is first of all being prepared and knowing to the best of your ability what to expect, being able to use the equipment you do have, and being able to improvise when you need to. (Dr. Mike Inniss, August 30, 2012)

Dr. Mike Inniss also recommend that teleparamedicine must not impair paramedics' abilities to self-check their performance, comfort, or ability to take care of themselves in the field.

Dr. Mike Inniss stipulated that teleparamedicine must support both paramedic's and specialist's ability to know how – and if – remote supervision should be performed. He indicated that successfully deploying teleparamedicine is mostly grounded in human behavior – and simply requires technology to remain transparent. He offered the example of how specialist supervision is already deeply ingrained in first-response teams,

> Its how a team works. We all have little areas where we are a little more proficient at than others. That's the way it is. I know, and I hope, my team members rely on me a lot for the medical practicalities of stabilization and extraction. At the same time, I am comfortable in the field, under most circumstances. That being said, I know that I rely on them for certain aspects of the rope work. I feel I can take care of myself, but as a team they are certainly there to make sure when I am assigned an anchor, or a raise, or a rope system that I am the one asking them 'Hey check this for me, would you.' Because it's not what I do every day. When they splint an arm they ask 'Mike check this, make sure this is good.' Because it's not what they do every day. (Dr. Mike Inniss, August 5, 2008)

Giving paramedics the ability to have a remote partner as a second set of eyes and ears to catch things paramedics miss or forget is not particularly novel. What is innovative is how WEHST supports a remote physician or clinician to help a paramedic sort through an unmanageable mass of sensory and situational information via a wearable platform of paramedic, semi-autonomously, and remotely controlled telepresence instruments. Therefore, when a great deal is going on in a short crisis period teleparamedicine needs to allow a wide swath of participants to mix multiple modes of media to allow those most familiar with the situation to share in the distributed and partly automated control of documentation, equipment preparation and operation, and dispatch or specialized resource allocation.[lxxx]

Paramedic training and corresponding knowledge already more or less gives them the ability to make correct choices in the field. Teleparamedicine simply needs to extend paramedic's scope of practice by improving the ability for remote physicians to make secondary assessments and share their broader knowledge base. Teleparamedicine is useful because it takes away responsibility of paramedics to *solely* decide whether or not to go ahead and treat. Therefore, teleparamedicine usability hinges on supporting paramedics' role of synthesizing and distilling everything on-scene into a bigger picture given to, and understood by, physicians.

The paramedic-physician boundary is fuzzy and goes both ways. Physicians vary in their understanding – and misunderstanding – of what paramedics can do. Teleparamedicine is useful when it buffers against confused supervisors hindering rather than guiding paramedic actions. While physicians benefit from increased situational awareness, this also translates into physicians not trying to micromanage something they don't fully understand. The quality of teleparamedicine is now, and will probably continue for some time to be, directly proportional to paramedics' capabilities to deal with the accident scenes. Sharon Pol says, "I've been to 400 car accidents. This is an environment I am friendly and comfortable in."

When paramedics arrive at the hospital and report how the patient is presenting, skilled physicians will want the details from the accident scene. In Sharon Pol's words, "What sort of intrusion into the vehicle was there? What position were they found in?

Was the windshield starred? Were they out of the vehicle? Were they up? Were they walking? How were they on scene?" Interestingly, many paramedics use cell phone cameras to offer multimedia evidence supplementary to the reports they deliver alongside patients when arriving at the hospital. The novelty of my proposed WEHST-based approach stems from how it supports the paramedic in offering more than verbal descriptions over the radio, permits the physician to participate in real-time in field-based multimedia production, and enables situationally appropriate safeguards to paramedic autonomy.

The design of the COMmand family of devices was based on advice and observations establishing how COMmand tracks, records, flags, and conveys communication. Communication breakdowns abound at the intersection of physiology, ergonomics, technology, geography, and climate.

> Electronic communication is always the first thing to fail. Regardless of how much we practice and how many times it works well beforehand, and also in BC geography is so unique and isolated, there are many areas where no electronic communication is available even if it did work. (Dr. Mike Inniss, August 5, 2008)

Communication is the thing all participants wished they always had. Direct links from the field to the wider team helping to extract or evacuate the subject will occasionally include colleagues offering higher levels of medical advice or care. While routine care does not require continuous verbal communication with supervisors, nonverbal communication is appropriate and beneficial in many work settings.

> Because we are working so intimately together, and sometimes under difficult circumstance, I think communication in the SAR [search and rescue] setting is very purposeful and very directed, there's not a lot of room for extraneous communication. There is a lot of non-verbal. You can see when a teammate's not comfortable with an open fracture or they can see you when you're not comfortable with a certain rappel or something. We count on each other to say "Hey you don't seem comfortable with this. Let's change this so that either you're comfortable or somebody else is". You have to perform with a pretty clear head in that sense and clear communication. (Dr. Mike Inniss, August 5, 2008)

Communication breaks down even in those scenarios where teleparamedicine capabilities are elevated sufficiently to justify having experts at a command centre. Becoming relevant in these group settings requires non-verbal communication fast enough for teams to respond quickly and with appropriately synergistic feedback.

Sgt. Ron Condly describes why context-specific feedback enhances group safety in high-risk environments.[lxxxi]

> Where I think there's value is where the environment is impoverished because of background noise. Where there's a lot of background noise or where we're dispersed. In mountain climbing environments – especially in a small team penetration into a vertical ascent or vertical descent. One guy is dealing with both of these lines, and the team lead will lose sight. By virtue of the terrain and where you're positioned you can lose contact. Especially where there's rushing water. (Sgt. Ron Condly, May 20, 2012)

Communication interruptions during helicopter external transport system problems are also addressable by hands-voice, speech-free control of communications capabilities. As a helicopter pilot, Dunc Wassick performs as communication hub and spoke – a mediator and intermediary – of communication *and* of real-time performance monitoring:

> My position is just direct contact with those I'm actually working with - and not other people - there's a lot of background noise that goes on. You have other people who are doing different missions who could be on different channels. But they may jam the air or interfere with work we're doing. They tell them to go to different channels. It's all talked about, as soon as you start to get a lot of noise on a channel. A lot of times our signals when we're flying are hand signals. Then there's no requirement (to compensate) for a breakdown in communications because of radios. We always have that for backup. If our radios go dead, or something goes funny - and that that seems to happen 50% of the time anyways. Our radios for some reason can't seem to communicate. So between the ground and the air we use hand signals. When the radios do work and you're on the right frequency it couldn't be any better. (Dunc Wassick, July 26, 2012)

Another problem with communication identified by Dunc Wassick is wind and air noise when rescuers are flying on the longline below him. When microphones overload and rescuers can't hear through their headsets, Dunc Wassick's communication channels are awash with the noise of blasting wind, and of people yelling and over-modulating their voices. Teleparamedicine oriented toward non-verbal and hands-free communication supports Dunc Wassick's role as the nexus of a helicopter external transport systems operation. Dunc Wassick has to remain attentive to tonal or postural evidence of anxiety or happiness during communication.

> Communications has always been a problem. Some people's voices are easy to hear over the radio and others you couldn't do anything about it. When that happens, then it just becomes hand signals and away you go. When you're working with people though you look in their eyes and stuff you can kind of read certain things – which you just pick up from experience. When you work with new people that takes a little while. Once you work with somebody you get that level of confidence working with them. (Dunc Wassick, July 26, 2012)

Sharon Pol's observations regarding communication patterns supported designing WEHST-based teleparamedicine to balance COMmand-centric and decentralized system architectures. Helicopter external transport system supervision by pilot and emergency manager is an ongoing multilateral process of checking in and turn-taking, with particular focus on the person on the end of the rope. The team-member least familiar with the whole helicopter external transport system operation requires constant mutual questioning regarding comfort with, and understanding of, tasks.

Helicopter external transport system operators ask, in Sharon Pol's words: "Is this the proper way to do it? Am I doing this in the right sequence? Is this how we want this event to play out?" Triangulating between paramedic helicopter external transport system operators, pilot, and emergency manager gives real-time feedback about how their blind spots diverge and converge. Closer communication enables a feedback triangle between the person on the rope, the pilot, and the event manager in the helicopter or on the ground.[lxxxii] As Sharon Pol adds, communication is key.

> 'Comms' are always the downfall. 'Comms' are always the thing that fails. So we can revert back to hand signals. Which is, yes, great when the pilot can see you at the end of the rope, or when the event manager can see you. But when there's that lack of visual you are flying free- you're dangling. As to how to stop your spinning, or ways to change your body position, we play with it when we practice flying. We definitely try and perfect it when we are on a call. If we had some – I don't know how, or what it would look like – some communication between event manager and pilot where he could fly differently, or change the position of the helicopter to change our position – go slower, go faster, whatever that would be. (Sharon Pol, July 25, 2012)

WEHST-based teleparamedicine is novel because it gives technical capabilities for making addressable those imperfectly understood and emergent communications states. Sharon Pol described how in environments where spoken communication is at a minimum. Requirements for interface transparency and enhanced meta-communication are advanced by most paramedics describing the best call being what multiple paramedics independently referred to as "the silent call".

> The dance. You hand me the thing I need before I ask for it because your partner knows. When you're doing a CPR call and you know that airway is going in, another thing is going in because your partner handed it to you because it was the thing you were going to do next. Yes. The dance. Yes, it's awesome. It's based on partner relationship. It is how well you work with that other person, how many calls have you done with that person, how many other mass casualties have you done with your partner. (Sharon Pol, July 25, 2012)

Sharon Pol described how teamwork is an intricate choreography which occurs in such proximity – and under such pressure – that bodily states are part of instantaneous communication. Paramedics are plural bodies in motion.

The design of the PSYchophysiology family of devices was based on advice and observations outlining how PSYchophysiology may detect, measure, record, flag, and generally translates paramedics' psychophysiological states. Verbal and nonverbal communication modes overlap with embodied self-monitoring techniques and self-tracking technologies. Challenging communication environments benefit from physiology-augmented control of communication technologies. Voluntary control of their own psychophysiological states makes paramedics more responsible for the safety and care of themselves – in order to be able to take care of someone else. Paramedics need to be skilled – and self-aware – enough to not fully rely on local or remote feedback to maintain their physiological equilibrium. Practical skills to cope and do well in all kinds of environments are based on experience avoiding and detecting dehydration, overheating, hypothermia, exhaustion, infection, or hunger.

COMmand's advanced communication capabilities are part and parcel with paramedic physiology-monitoring capabilities that Al Craft identifies as relevant for training rookies and new recruits. Each recruit is different, proceeds at different rates through training and has different comfort levels with doing their job. Al Craft and all other participants described telehealth focussing on the paramedic's safety and peak performance as a distinct approach from the wider emergency-management-community's focus solely on the patient.

Sharon Pol advised that positioning or producing commercial teleparamedicine products for successful long-term adoption would be through PSYchophysiology-enabled evaluation and comparison of bodily states. Sharon Pol pins teleparamedicine's value to how well it improves team cohesion through capabilities to assess or understand people's uncertainties within particular settings. "There is value in knowing what causes stress in certain people. To me kid calls bug me. So it would be nice to be able to get feedback as to how I responded on a kid call versus an 'unknown 60-year-old' event."

Synchronous supervision of someone having anxiety at step A, B or C will completely change how individuals are trained or whole teams are oriented. This includes varying the learning pace, surveillance, and field operator autonomy to match the situation. While after-the-fact review of all types of WEHST-based documentation of the call may examine why or how things go right or wrong – PSYchophysiology monitoring has particularly concerning ethical, moral, legal[lxxxiii], and professional ramifications. Body-monitoring would add depth and complexity to the routine debriefings already performed within paramedicine, search and rescue, and helicopter external transport systems communities – with varying degrees of delicacy. As one of my participants, Sharon Pol, put it:

> Not so delicate at times, but yes. We talk amongst ourselves, truly. It is hard to bring up to people when we work together, because we are a fairly tight knit community, because you don't want to hurt somebody's feelings, you don't want to make them hurt. You don't want to strain or damage working relationship you have. Sometimes it is difficult to bring up tough subjects. Like if you disagree about how a patient was handled on a call, it's very, very difficult. (Sharon Pol, July 25, 2012)

Rene Bernklau was also a strong proponent of paramedic psychophysiological monitoring for chemical-biological-radiological-nuclear-explosive training and response. For example, paramedic psychophysiology in mass-casualty-incident response is potentially part of decontamination and public health follow up. Mass-casualty-incident has a large psychosocial obligation to immediately address concerns for how responders themselves are affected, and then – hours or weeks later – addressing the general public and media. Rene Bernklau described how short-and-long-baseline psychological and physiological fitness monitoring is among the most useful attributes of teleparamedicine:[lxxxiv]

> We see on an average July-August a good example of very hot fires. We probably respond to anywhere from two to 24 fires every 24 hours within the province of BC. And

this has been an extremely busy fire season from January on. We see that enough that - when we're doing rehab and rehydration – out all those calls – say 24 per day for seven days, we're probably carrying seven to eight firefighters to the hospital. Just on what we're finding on vital signs. Hypertension or hypotension, it's rarely related to heat stress or the exertion that they put out. There's underlying medical conditions when you get to be 40. We're all guys. When you're 40 years old you don't go see a doctor. You don't get your cholesterol checked. Where this always comes out is in the heat of the battle, or after your tour with an SCBA [self-contained breathing apparatus] and you really 'put out' in this fire. (Rene Bernklau, August 30, 2012)

Rene Bernklau's description above shows how psychophysiological and environmental factors are linked. The design of the POSition family of devices was based on advice and observations outlining how the POSition devices may sense and act upon their physical environments. Environmental and psychophysiological monitoring may be particularly useful in tandem when seeking to stabilize communication in the face of voluntary and involuntary perturbations.

Monitoring movement, microclimates, and ambient environments finds environmental and behavioural correlates for psychophysiological *and* communication abnormalities.[lxxxv] Furthermore, monitoring also can contribute to tracking the gear on the ambulance and the fire trucks.[lxxxvi] The performance metrics and coordination of people and material are feedback valuable to incident command.[lxxxvii] According to Rene Bernklau, monitoring the team's environment and matériel is much more than a means of ensuring robust communications. Environmental monitoring also addresses physical safety concerns presently unrealized and inadequately studied:

You know there are issues other than 'comms' when you deal with all five senses. I've got responders that can't smell. I don't want them in the area of anything if they can't smell. Because I want that first smell to be your warning sign to get the hell out of dodge. I'd be looking for somebody that sits with him so that somebody can smell. You can use some form of detection and that sort of stuff – still if you've got a gas leak I want somebody to be able to smell Mercaptan. I've got people that can't taste that stuff. I look at all the different types of people with optometry challenges. Color blindness is enough. Short-sighted, longsighted, contact lenses. (Rene Bernklau, August 30, 2012)

The POSition family of devices makes communications more robust by continuously rebuilding a spatial and environmental awareness – across a spectrum of hazards fluctuating within – and across – sites. This WEHST-level "environmental awareness" adds richness to the multiple modes of media that the entire system generates.

The design of the MEDia family of devices was based on advice and observations outlining how the MEDia devices record and display audiovisual multimedia. While the entire WEHST system is a wearable recording and playback platform, MEDia is perhaps the most widely recognizable media mode. Ian Cunnings advised that producing and managing the medical records of both patient and paramedic in real-time raises concerns about integrating overwhelming amounts of audiovisual multimedia into contemporary medical databases.[lxxxviii] Conducting and recording missions, and then analyzing the evidence, necessitates delegating human and technical resources to manage the data collected and the overall program.

> What I 'm struggling with is who's going to evaluate it. So now, you look at it from a scale of economy – We're a limited budget in BC, a volunteer based SAR [search and rescue] program that at the provincial level has one person that's assigned for providing some facilitation of that. Now I'm working with a number of other partners, but in terms of the staff time within *Emergency Management BC*, SAR is 2% out of 100% of what we do in terms of support. But if you look at call volume we have 1000 SAR calls a year. How many floods do we have a year? Well we don't have 1000 floods a year, but the impact is greater. So the amount of time regional staff spends on SAR isn't in proportion to the calls that are going on. (Ian Cunnings, August 30, 2012)

MEDia produces paramedic-and-patient-oriented multimedia that becomes part of their medical records collected, knowing what to do with it depend on how the intrinsic research capabilities of the WEHST platform have been configured to protect the privacy of all participants.[lxxxix] For example, setting expiry dates on data and purging it periodically is only one approach. Demands for longer-baseline datasets could also create opportunities for government databases for particular regions, institutions, professions, and incidents; each community of practitioners requires different anonymization strategies.[xc] This decentralized partnering also consolidates management of technical, regulatory, and legal requirements around storing patient and employee records. Ian Cunnings described contemporary concerns around ownership and consent:

> Who owns the data? It's my data, you're taking it from me, and do I own it? Or, does the organization I work for own it? Or, if I'm a volunteer working on behalf of another agency, does that agency own it? What's the data sharing agreements and governance? […] When you're collecting something as personal as my heart rate and blood pressure, I may want to say I don't want that information shared really. So how do we get back the intellectual property after it's collected? Consent is an ongoing process. If I'm wearing this equipment who benefits and who pays? So there's a benefit to the organization that I work for: that they're in some way able to monitor my health and safety; or, in the training environment teach me how to do it better. Which is good, and there's a direct benefit to me there. But now you've got the information that's collected benefiting somebody else. (Ian Cunnings, August 30, 2012)

In summary, the range WEHST-based teleparamedicine emerges from interviewee-informed design for the flexible and mutually reinforcing interplay of the four "first" families of COMmand, PSYchophysiology, POSition, and MEDia modules. Furthermore, the robustness of WEHST arises from the four "second" families of HUB, POWer, PROcessing, and MEMory stabilizing the interplay among all WEHST constituents – including accommodating the teleparamedicine-wide concerns for, and of, emergent hybrids of human, technical, and ecological actors.

5.3 What made it into the design of the WEHST "objects"

What made it into the teleparamedicine system-level design arises from a WEHST design constrained by ethnographic findings. WEHST toolsets address conspicuous gaps in the quality of life and health of both paramedics and patients. Expert interviewees reported experiences and offered informed speculations applicable to identifying and modelling human, technical, and environmental hybrid actors. To address the real needs of prospective stakeholders I apply ethnographic findings towards generating evidence-based solutions suitable for comparison against existing solutions.

This design project is not just for the sake of the exercise of making something for the sake of making it. WEHST addresses an opening in the marketplace of products for addressing real-world technical, legal, ethical, moral, political, economic, and ecological concerns. The WEHST design project proposes a significant leap forward in the wearable telehealth product category; and may in fact introduce an entirely new product category of platform technology for wearable human-based computing *and* situated computing.

Field study participants contributed to establishing ergonomic criteria encompassing physical aspects such as personalization or sizing – and introduced concrete factors of size, weight, color, durability, and strength. Additionally, psychological criteria were gathered, pertaining to the personal meaning of devices or processes such as reducing stigma associated with medical products and cultural measures promoting user identity.[xci]

Significant contributions were aggregated from all participants toward the designed object are synthesized as the following five (fuzzily delimited and thus somewhat overlapping) characteristics: First, WEHST enables hands-and-voice-free communication via, and control of, their radios. Second, WEHST is wearable and configurable on-the-fly. Third, WEHST-based telepresence blends documentation, management, security, and analysis. Fourth, WEHST teleparamedicine uses concurrent artificial intelligence, remote supervisory, and paramedic-in-the-loop control systems to adapt to telecommunication limitations. Fifth, WEHST detects and mitigates physiological states and environmental) conditions impairing operator communication or reducing situational awareness.

First, this technology must enable hands-and-voice-free communication when field-operators' hands and voices cannot reach their radios. Current hands-free communication techniques of speech recognition or voice activation are frequently problematic in formal hazardous substance response settings. While a few teams with closed communications systems make limited use of speech recognition and activation, this breaks down often and is used so rarely that the cost becomes prohibitive.

Anecdotally, most organizations bypass hands-free communications and put up with several days of inadequate communication per year. This willful inadequacy indicates a requirement for offering various degrees of combined psychophysiology-triggered control of paramedic radios. For example, a voluntary jaw clench can be an electromyography-based physiological trigger augmenting (or instead of) regular voice activation of, and speech recognition by, radios in environments with excessive background noise.[xcii]

Hands-and-voice-free communication via voluntary (and occasionally involuntary) bodily control leaves also leaves paramedics hands free without impairing ability to speak – or risking swamping their communication channels with the ambient noise or chatter associated with patient care. Hands-and-voice-free switching of radio channels or modes aids paramedics to communicate while coping with sensory, cognitive, and physical overload.

Second, the proposed WEHST system must be wearable and configurable on-the-fly to balance paramedic and remote supervisor capabilities against contextual demands. The requirements for WEHST is similar to the general criteria for search and rescue gear: crush-proof, drop-proof, immersion-proof, dirt-resistant, sterilisable, light and durable, user-friendly controls workable with medical *or* thermal gloves, perceptible displays, reliable power sources and giving vital signs for paramedic *and* patient. To make wearability work in the wilderness-safety environment, it must not add weight nor compromise the body's ability to breathe or shed water; or to cool down, maintain temperature, or heat up in a safe fashion. Real-world environments introduce a range of temperature, humidity, abrasion, corrosion, vibration, immersion, or (de)pressurization conditions. Very few circumstances accommodate big, bulky matériel vulnerable to environmental perturbations.

In Dr. Mike Inniss' words wearable body monitoring needs to be "weatherproof, lightweight, and durable." His requirements were explicit: small, sleek, sealed, and insulated equipment fitting into a pack or worn on the body. These criteria drive design of an energy, time, and space efficient, and shock-resistant teleparamedicine platform for the field.[xciii]

Furthermore, the wearability of WEHST makes modularity paramount, as “kit triage” by search and rescue helicopter external transport system operators is led by self-sufficiency responsibilities foremost. Teleparamedicine and paramedicine capabilities are triaged against self-rescue and survival in adverse conditions. Moreover, team-sufficiency is also of great concern, as each member does “kit triage” in order to work within narrower areas of specialization which simultaneously reduce redundancy and extend the whole team’s capabilities:

> The rope team-leader might have half his pack full of rope gear for the team, and half of my pack might be whatever medical gear I can carry. Everybody would have their self-sufficiency first aid kit, but I am responsible for the larger one for the group. Not only are we triaging subjects and patients, but we are triaging what gear we carry. […] As you wean down in your travel needs to go light and fast, you triage your gear – and you often leave a trail of gear. We certainly have to approach it as a modular system – which you pare down as your needs for efficiency, lightness, and speed increase, what you take in decreases. Sometimes you can have a mule train of people bringing your stuff in later. There’s an initial response hasty team that goes in. maybe I’ll just go in with my own stuff. Stabilize somebody and asses, and then call in what I need, and then it gets flown in or brought in. every situation is so different it’s hard to generalize. A modular system is good so you’re prepared to quickly wean down what you need and toss things that you don’t. (Dr. Mike Inniss, August 5, 2008)

Sgt. Ron Condly proposed a mixed form of wearability appropriate for adoption by institutions with rigorous safety cultures. This approach has a core architecture built on an oft-worn garment with a basic configuration for adding and subtracting plug-and-play computing modules and sensors.[xciv] This garment, accompanied by a small suitcase of basic or advanced peripheral components, lightens the “burden of ownership” as appropriate configurations emerge and adapt through practice *and* regulatory oversight.

Sgt. Ron Condly described how the search and rescue technician's kit is tightly circumscribed by their practices, and new configurations[xcv] are provisional on years or decades long evaluations of paramedic safety[xcvi]:

> In the SAR Tech [search and rescue technician] role it is so specific we are very reluctant to move off our current configuration. Because our current configuration is generally there and it's probably gained that corporate information based on blood. Somebody has hurt themselves, somebody has been injured or died, and we've learned our lesson corporately. There's going to be corporate reluctance to move off current techniques. (Sgt. Ron Condly, May 20, 2012) [xcvii]

Overall, wearability and modularity are practically synonymous for real-world teleparamedicine equipment. The modularity of the basic hardware and software architecture enables paramedics in the field to plug in and plug out of various sensing, communicating, or data-gathering capabilities to give value to a range of responder and technology networks, and environments.

Third, accomplishing real-world-ready WEHST is through adaptive telepresence interfaces blending documentation, database management, bandwidth management, network security, and paramedic-performance analysis.[xcviii] Sgt. Ron Condly outlined how telehealth documentation capabilities are comparable to existing off-the-shelf solutions. This extends to scenarios where legal cases and boards of inquiry may request or require real-time quantitative measurements of operations in hazardous environments. Such measurements are also legally relevant for quantitative analyses and qualitative evaluations made in later reporting on impacts of toxicity or loss of life.

> *Transport Canada* accident investigators, *RCMP*, and *Coroners Service* all use data from giving us cameras to go into a plane crash. Prior to entry – obviously life taking precedence – we'll take a picture from on high, we'll take a picture once we get down, approaching the crash scene, and continue until we find the people. We deal with the injured first off. Anybody deceased we take a picture in position. Documentation for

> *RCMP*, *Coroners Service* and *Transport Canada* has certain parameters. If there is a dashboard, or if there is a control console, we'll take pictures of those. So those are all part of the documentation that goes into the accident investigation. (Sgt. Ron Condly, May 20, 2012)

Sgt. Ron Condly proposed how the incoming generation of paramedics are prepared to integrate telepresence in daily practice as an "assumed technology" and take wearability as the value statement:

> I think it's what the organizations that are coming – and our leadership and other agencies – demand: new information whether it's legal information, technical information, tactical information, emergency information. Whether or not those people want it I think that if you have that capacity at the garment interface it has efficacy. (Sgt. Ron Condly, May 20, 2012)

Sharon Pol observed how teleparamedicine changes the paramedicine environment by offering feedback at the levels of individual, team, institution and trades:

> People get into a pattern and a familiarity with how you do things that you can familiarly do wrong – because it is a classic pattern. From lifting to stepping out of the ambulance; anything you can do, you can consistently do wrong. If we had information or feedback when we were washing the ambulance or cleaning up our equipment after a HETS call: It might identify a space limitation where we have to do something awkwardly or strangely because of the storage space, storage equipment, the containers we keep stuff in, how we organize our equipment. (Sharon Pol, July 25, 2012)

A particularly prescriptive description by Sharon Pol was of how documenting and analyzing[xcix] what paramedics and patients touched (and where they moved) offers precautions against infectious disease; reduces uncertainty added during the call; and guides and tracks site, vehicle, patient and paramedic, equipment, and hospital decontamination:

> How *do* we clean up? What precautions *do* we take? Because that information is not necessarily something that's part of our training. It's something that's learned on the job. As we all know, with any job we don't necessarily learn the right way to do it. Time is key there. You never get a second chance to do that call again. You never do get that.

> *Where* was that point of exposure, and *when* was that point of exposure potentially. (Sharon Pol, July 25, 2012)

Sharon Pol highlights how case-by-case learning – and teaching - on the job is part of paramedicine practice which offers an immediate use for teleparamedicine.

Fourth, teleparamedicine systems require concurrent artificial intelligence and human-in-the-loop control systems to readily and rapidly adapt to telecommunication constraints of bandwidth, processing, compression, encryption, networking, and latency. Teleparamedicine systems benefit from human-in-the-loop concurrent control systems to readily adapt telecommunication parameters to telecommunication constraints. For example, a real-time live-feed of paramedic perspectives from the ground is only helpful to emergency managers (such as pilots) if they have adequate time during an emergency situation to quickly review media. These circumstances are an opportunity for limited artificial intelligence on-the-body (or in the "cloud") to continuously tune WEHST performance to match telepresence requirements with dynamic telecommunication network capacity.

Remote and autonomous capabilities for optimizing WEHST performance also increase the scope of deployment beyond what an unassisted paramedic could accomplish. For example, Dr. Mike Inniss indicated a probable decision point to wear WEHST at around twenty minutes worth of telepresence. Less than twenty minutes of usability may lead to deciding to not bring teleparamedicine into the field. Dr. Mike Inniss was clear that wearability is even more valuable if twenty minutes of high-quality telepresence can be adjusted to stretch 40 or 60 minutes of telepresence over four hours. Such optimization of telepresence requires making trade-offs among the telecommunication constraints of bandwidth, processing, compression, encryption/decryption, networking, and latency.

Sgt. Ron Condly likewise shared several examples which showed that the proposed decentralized teleparamedicine control architecture of WEHST would give value at short range. For example, body-worn telepresence systems remotely operated by another team-member in the field over short ranges reduce the risks of having to reach around, move their bodies in certain ways, or crane their heads to obtain a certain point of view.

Fifth, this human-in-the-loop control scheme must detect and mitigate (physiological and environmental) circumstances of impaired operator clarity of speech and hearing, attenuated metacommunicative competence, reduced situational awareness, or diminished perceptual acuity. The WEHST system needs to generally correlate (in part through synchronous and asynchronous coding within human-based computation schemes) these diminished capabilities with particular psychophysiological and environmental stressors. For example, debriefing paramedics after a mission (routine or not) requires evaluating performance under stress by correlating their psychophysiological status with environmental conditions. As Sharon Pol describes, these quantitative cues identifying previously undetected, under-reported, or misattributed workplace stress:

> Feeling. You can’t really see it in yourself and other people can’t see it in you. It’s hard to know how other people are feeling. So it’s hard to name the feeling. Sometimes people don’t even recognize it in themselves. They might not be familiar with feelings of anxiety, or they might not be familiar with a sense of loss, or disappointment, or the elation sometimes you get. They might not be familiar with those feelings, and it might be

> baffling to them, so yes to be both – to even pinpoint that there is a change in a person. (Sharon Pol, July 25, 2012)

Increasing general awareness of what senior and junior members are doing in a quotidian setting includes heightening specific awareness of individual preparedness for exceptionally stressful or risky circumstances. Al Craft indicated telepresence would be useful for a team by giving a means to combine managers' and team leaders' experience of what is "normal" while coordinating and evaluating the performance of individual team members.

Hence, WEHST offers augmented – not entirely new – mechanisms for monitoring performance cues of, and self-evaluations by, paramedics.[c]

> We're careful – when we know it's likely going to be a fatality or a recovery kind of a thing – who we put in. if it's a first time for somebody we'll make sure that they're with somebody who's senior and has been there and done it. It makes the whole thing a lot easier. We get right into the critical defusing thing after too. We're firm advocates of doing that. Any time we do have a serious recovery that's nasty or whatever, then we make sure we provide the critical incident debriefs. If you can see a change in the way that person is behaving or whatever – then you're going to pull them out of there. We're all going to go through levels of ups and downs with this, but if it's starting to impede the way things are going, or we can see this is not going well – then yeah, we'll just make that effort. Again, that's experience and making sure your senior people are up on that, but that again is from experience. (Al Craft, July 23, 2012)

All interviewees indicated a linkage between physiological state and environmental conditions – with consequences ranging from physiological collapse to psychological stress. For example, environmental monitoring of a paramedic going into a chemical spill may give them immediate awareness of changes in wind direction when navigating around obstacles; or track the concentrations of invisible hazards fluctuating in microsites responders are moving through. Paramedics responding in enclosed spaces and many industrial sites would benefit first from real-time environmental monitoring for carbon dioxide, carbon monoxide, and sulphur-bearing toxic gases.

While wind speed, temperature, or other ambient conditions are secondary considerations for primarily medical rescue calls, physiology may be profoundly and rapidly impacted by how it is positioned in its environment.[ci] For example, during real crises, paramedics in the heavier variants of personal protective equipment remain in the field 20 to 30 minutes – long enough to induce significant psychophysiological stress.[cii] Rene Bernklau described how WEHST augmented monitoring and communication capabilities could scale up from a simple connection between radio and paramedics' body, to improving the multiple microclimates of bodies, personal protective equipment, and proximal environments:

> That's part of our problem with our response capability. We don't have the assessment skills in the frontline of most of our major response agencies to determine "Okay this is this type of [chemical-biological-radiological-nuclear-explosive] product, so we can downgrade from a level A to a level B or a C suit and keep our responders working longer." Heat stress was another issue. Level A is definitely heat stress – our last set of PPE [personal protective equipment] was a charcoal-Gore-Tex type suit – heat stress again was an issue. We've now downgraded to a system that has a flow of air all the time, and we've found that it's now the other side – it's a cold stress. We initial start sweating, then we calm down and do all our work – and if then a cold wind pops up and all of a sudden its hypothermia versus hyperthermia. We're looking at accommodating both sides of that sort of thing. (Rene Bernklau, August 30, 2012)

Personal protective equipment worn in extreme environments creates multiple microclimates around the body. The diversity of body types – and body parts – adds complexity to controlling and assessing physiological fluctuations. For example, during the several hardest days of the year rescue teams working in a chemical-biological-radiological-nuclear-explosive scene may require more extensive – and better managed

– monitoring. Keeping in line with current best-practices, WEHST deployed during large-scale responses would permit ambulance teleparamedics both physically on-site and remotely, to do a wellness check. Ian Cunnings described how wellness may be evaluated through combinations of blood pressure, temperature, heart rate, pulse oximetry, respiration, skin conductance, electroencephalography, electrocardiography, and electromyography using base standards of age, sex, and weight to set physiological target ranges to meet. Ian Cunnings described how if a paramedic misses their range they rest before returning for re-evaluation at approximately 30 minutes later, until they are good to go back out in the field.

> It would be fantastic from a searcher safety perspective to be able to have [wellness checks] done automatically. So a based on - I don't know if a baseline would be a personal one or a standardized one. […] If you had something where you could do that automatically the search manager or the safety officer would be able to look at it and go "Okay, look Ian is working at 20% above his zone. Time out Ian. You should probably have a rest." or, "Oh, look what he's hiking up. Give the guy a break. However, if this goes on for another couple hours…" (Ian Cunnings, August 30, 2012)

This group of paramedics all reported needs for telepresence extending across very short and long spans of space and time; and from across the multiple sites on the surface of single or multiple bodies and ecosystems. In conclusion, all of these emergency-response practitioners contributed to developing and maintaining a specific WEHST pattern grounded in building and maintaining the WEHST partitioning strategy of COMmand, PSYchophysiology, MEDia, POSition, HUB, PROcessing, MEMory, and POWer. WEHST's complex relationships with patients, personnel, matériel, procedures, and environments underpin the wearability of all manners of remote teleparamedicine actors.

Chapter Six: Industrial Design Process

6.1 Journals and sketchbooks

> An ‘actor’ in the hyphenated expression actor-network is not the source of an action but the moving target of a vast array of entities swarming toward it […] To use the word ‘actor’ means that it’s never clear who and what is acting when we act since an actor on stage is never alone in acting […] Action is borrowed, distributed, suggested, influenced, dominated, betrayed, translated.[123]

This chapter begins with textual analysis of how the whole arc of teleparamedicine, WEHST, and COMmand design processes were approached as complex adaptive system design at multiple scales. The latter half of this chapter draws from my archive of sketchbooks, notebooks, prototypes, and 2D and 3D digital files and folders to present in images and text a distillation of design processes uniting the human-mediated teleparamedicine system, WEHST toolset, and COMmand module.

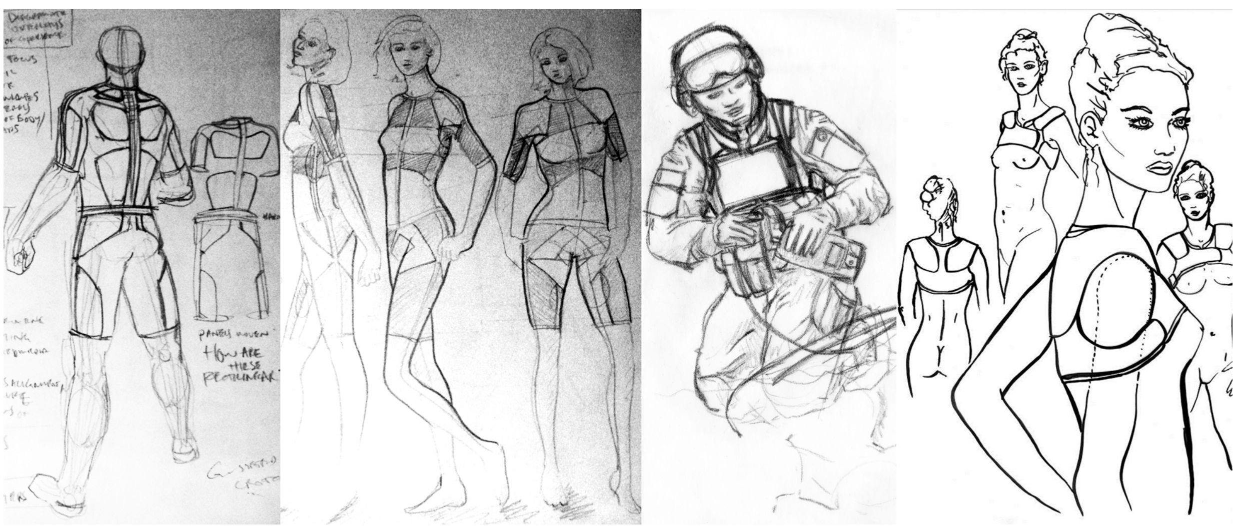

Figure 6.1: Left to right, wearable human-mediated teleparamedicine undergarment pattern development process, pencil sketches, 2009; telepresence vest sketches and brush and ink study 2010. These images are snapshots from processes leading up to more recent designs which have focused on alternative interpretations of the term ‘textile’. Current HMTPM designs instead consider the hypothetical garment systems shown here as WEHST peripherals for specific use-cases.

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[123] Latour*, op. cit.* Reassembling the Social. 2005. P46

My design process deployed a multitude of design tools by synthesizing writing, drawing, diagramming, sewing, and sculpting into a “thing” capable of system-level adaptive responses to complex environments. Relevant teleparamedicine design processes, as continuum of non-unitary and non-local phenomenon, converge through development of a human-scale WEHST’s multiple subsets and variants. This adaptive design offers a technical solution to the wicked problem of cohering complexes of medical personnel, medical populations, medical instruments, and medical ecosystems into teleparamedicine actants.[ciii]

ANT was developed to analyze situations in which it is difficult to separate humans and non-humans, and in which the actors have variable forms and competencies.[124] ANT gives a non-reductive approach appropriate for complexes of ecosystem-level processes. ANT is congruent with the scale of the “super-wicked problems” [civ] facing all organisms on earth (the ecosystem is an actor as supported through the Gaia hypo/thesis)[125], of which all designers are responsible to be concerned. However, if complexity is considered as normative, and teleparamedicine design is approached as ecosystem-situated computation, then processes may be conducted to make teleparamedicine workable without oversimplifying it. A particularly apt description of this approach is Zellmer *et al*’s constructivist approach to countering over-simplification of ecological complexity.

Applying Zellmer’s injunctions throughout my design process prevents establishing too many levels of constraint. Furthermore, these few levels are linked with

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[124] Callon, o*p cit.* Actor-network theory - the market test. 1999. P183
[125] Lovelock, James. E. (1990). "Hands up for the Gaia hypothesis". Nature 344 (6262): Page 100–2. 1990.; and, Margulis, Lynn. Symbiotic Planet: A New Look At Evolution. Houston: Basic Book. 1999

purposely fuzzy criteria to postpone emergence of deeply hierarchical product architectures. Correspondingly, I applied in parallel the inverse of Zellmer's approach (which she and her colleagues also explicate in detail) in order to simplify teleparamedicine phenomena just enough to be wearable with contemporary technologies. This does not oblige a realist view of ecology, and in fact entails its inverse: a constructivist reverse engineering of realist perspective to calibrate an ecological perspective of situated non-unitary non-local actors adapting as, and in, complex systems. I concur with Zellmer (and she with Rosen) and appreciate complexity cannot as neither adequately modelable nor explicable from a realist viewpoint.[126]

> The authors here have asserted elsewhere measurable characteristics of what makes something complex. We now recant that error. We contended that complex systems are deeply hierarchical, the deeper the hierarchy the more complex they are. Complexity in those terms displays many levels of constraint. The constraints, we said, are linked with explicit aggregation criteria. We continued by asserting that complexity invites links between large and small scale, and between fast and slow processes. Complex systems have explicit links between multiple types, or equivalency classes. To deal with a complex system it must be assigned to an explicit type, and be given an unequivocal boundary. In all this, at a fundamental level, we were wrong. But now, in the light of our desire to define complexity as something normative, we see a striking reversal of what is simple as opposed to complex.[127]

Zellmer et al. propose "a scheme for making complexity tractable," which first fits my own design cognitive processes. Secondly, Zellmer's scheme makes the complex WEHST product system controllable through technical design of computational textile objects with internal processes approximating how:

> In a pair of cycles, one reinforces patterns of model building, and the cycle of the other deals with the changes that appear in the essence of that which is modeled. We use

[126] Complexity after Robert Rosen 1934 – 98, American theoretical biologist.
[127] Zellmer, A.J.; Allen, T.F.H.; Kesseboehmer, K. The nature of ecological complexity: A protocol for building the narrative. Ecological Complexity, Volume 3,. 2006. P173

> narrative to rise above the local constraints of models. In the end, […] we build a narrative from a set of separate models.[128]

Zellmer et al.'s process guides my interweaving of complex assemblages of actors throughout my industrial design project. My research has approached platform technology design from an ecological perspective, and the vast actual and potential complexity of the resulting teleparamedicine system remains unreduced. "In the end, we found that narrative is the favored device for addressing complexity. It is robust, even when models break down."[129] In consideration of Zellmer, my resultant designs arise as narratives *about*, but not as, (narrowly reduced) feedback linkages among large and small scales and fast and slow processes. However, concrete feedback occurs during normal use of the system in typical procedures. Multiple types of technical, biological, social, and ecological subsystems are explicitly linked to create an unequivocal boundary of the whole product.

WEHST's non-unitary and non-local computational textile architecture demonstrates the inadequacy of "realist metaphysical assertions as to material nature and external reality" when designing for irreducibly complex actants and situations.[130] Computational textiles are the nominal paradigm guiding my WEHST design. However, fabric or textile is too flexible (and entangled with human embodiment) to reduce to less than a narrative. Textile is thus an appropriately partial and incomplete paradigm. Similarly, WEHST modules constitutions are as – individually and in aggregate – open-ended hybrids of digital, analog, human, and otherwise situated wearable computation.

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[128] Ibid. P171
[129] *Ibid.* P82
[130] Zellmer, Allen, and Kesseboehmer, *op. cit.* The nature of ecological complexity. 2006. pp171–182

WEHST's technical specification is of customized and personalized constellations of modules and concomitant electronic textile interconnections offering an instance of human wearable fabric computing.[cv] This computing fabric design comprises flexible structures integrating dense multimodal arrays of partly redundant distributed sensors, emitters and embedded systems linked by feedback loops. Computational textiles arise when composite woven textile structures containing electrical circuits formed of interlaced conductive and non-conductive threads carry and connect WEHST modules via embedded sockets.

Groupings of WEHST modules may be worn in multi-agent system (MAS) montages as a wearable fabric computer. These proposed multi-agent systems emerge through combining technologies for distributed computing, distributed operating systems, parallel programming, and parallel processing. WEHST is deployable as combinations of module families on, and among, paramedics whose interactions at multiple scales within their environments solve difficult problems.

WEHST design comprises combinations of eight distinct families of modules with capabilities. I furnished these families with descriptive family designations of *PSYchophysiology, POSition, MEDia, COMmand, PROcessing, MEMory, POWer* and *HUB*. Each family contains one or more distinctive types of individual intelligent agent (which is semi-autonomous) which coordinate the performances of multiple subordinate, smaller, and less-reflexive peripheral modules. Resultant multi-agent systems are assembled from up to eight types of WEHST agents and one or more (local and remote) human operators. WEHST's eight types of discrete artificial-intelligence-enabled modules is each a single agent. Each respective agent remains a bounded subsystem performing specific types of interior processing. The system likewise functions autonomously, or with multiple local and remote human operators.

WEHST's assemblage may also be considered a flock or swarm that has no central executive. WEHST swarm behavior is analogous to the dynamics of guideline-based care within larger teleparamedicine systems, in which control is often decentralized or multi-centred within discrete modules. The interior processes of discrete modules, such as the COMmand module, are also a swarm or flock of multiple parallel processors. The whole-system behaviors of stand-alone COMmand devices, WEHST modules, or teleparamedicine systems of systems are instances of distributed control arising from local interactions.[131] These local associations bring appropriate – or unavoidable – actors from wider telemedical ecosystems into this swarm. System-level self-testing is required for swarming.

Paramedics and first responders in high-risk environments configure and position their matériel to perform as a 'black box' testing platform for operator, hardware, software, personal protective equipment, and environment. Black box testing of higher-level teleparamedicine and unit-level WEHST and COMmand examines functionality of teleparamedicine actors without obligating access to complex internal structures. These relationships are unfolding too fast for real-time analysis.[cvi]

High-risk situations position COMmand as a black box wearable-data-recorder combined voice and data recorder and emergency locator.[cvii] The technical envelope of COMmand spans capabilities similar to *flight data recorders* (FDRs); and similar to commonly used yet rarely acknowledged *automotive event data recorders* (EDRs).

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[131] Holland*, op. cit.* Signals and Boundaries. 2012. P7

Performing as a data recorder COMmand offers synchronous or asynchronous remote monitoring or recording as a matter of configuration of basic onboard device capabilities. On-the-fly configurations are required to suit monitoring to those jurisdictions the data falls into.

WEHST protects the paramedic wearing it from broken bones, ruptured internal organs, abrasions and contusions or chafing. Individual WEHST devices are small, without protruding features, sharp edges, or corners. This smoothing is essential for paramedics and search and rescue operators doing helicopter operations or jumping from airplanes. The industrial design process of this “data recorder” for teleparamedics combines bodily, technical, and environmental performance. However, this assumes it is possible to overcome the significant ergonomic limitations of contemporary technologies through a swarm-based architecture grants.

Simply, WEHST is sized and weighted in such a way as to reduce risks to a paramedic’s life and well-being. The small range of sizes of individual submodules comprising WEHST are granular and distributable to remain flexible enough to prevent or reduce interference with the fit and feel of harnesses, backpacks, uniforms, and other body-worn matériel.[cviii] WEHST’s highly adaptive lightweight architecture is designed to be gradually and cautiously integrated into moment-by-moment configurations of uniform and personal protective equipment ensembles. As telehealth is an emerging practice, WEHST offers multiple variants and configurations of field-based telepresence systems.[cix]

WEHST may also be configured in multiple weights and densities. For example, WEHST montages for varying degrees of augmentation of paramedic telepresence-mediated care-giving may weigh from one to three kilogram (kg). Field studies indicated this one to three kg weight is the upper limit of what professional first-responders are prepared to add to their existing mandatory equipment load. A minimalistic WEHST instantiation as a practical lightweight telepresence system is in the one kg range and operates both synchronously and asynchronously, while offering both high and low-bandwidth audiovisual signals.[cx]

WEHST modularity arrives through deconstructing previously integrated systems into networks of semi-independent and fully independent sub-assemblies. Granularity enables distributing the mass and volume of the system into multiple submodules. The modularity of WEHST generally makes field serviceability possible in terms of repairs or upgrades. Genuine serviceability obliges not fully replacing the highly specialized hardware and software components extensively and continuously personalized for specific individuals and tasks, or located in remote locations. WEHST personalization includes tuning the coordination among multiple types of processing modules, and a range of modes among sensor and effector arrays.

WEHST is scalable at more than the technical network level. WEHST permits different team-sizes or structures, individual degrees of expertise or specialization, or unique operational requirements or environments to be factored into the various system performance metrics. WEHST scalability means the number and types of sensors, the battery capacity, wireless range, number or type of processors. Specific requirements of multiple types of remote specialists can be factored into how the system is configured on the paramedic’s body during training or deployment. WEHST scales on-the-fly for human-mediated telepresence in first-response, medical, telemedical or nonmedical crisis-management applications. Highly variable team-configurations and deployment-contexts required may range from one to hundreds of local and remote operators.

WEHST scales at levels of the hardware, firmware, middleware, and software applications worn on the paramedic's body. WEHST's sub-networks of sub-assemblies may be fully-subordinate, semi-autonomous, or fully autonomous. Coordination between centralized or decentralized control allows field-based agents to work in conjunction with network administrators and remote supervisors to change or challenge the boundaries of their wearable telepresence system during normal use. WEHST scalability enables individuals and teams in the field to select and calibrate sensing and processing combinations appropriate for their conflicting top-down and bottom-up professional, regulatory, actuarial, practical, technical, or individual control requirements.

WEHST's adaptivity arises from system-level configurability to accommodate multiple personalization grading's for individual bodies. WEHST adaptability extends to the wide range of training and deployment scenarios and the high degree of variation in skill, experience, and learning ability found among paramedics.[cxi] WEHST modularity permits personal ownership of some of the more physiologically-centered and personalized modules of larger montages. WEHST's complex adaptive behaviors arise from internal signaling networks in order to coordinate the multiple device modules and multiple human agents in the conservation of limited resources. Multiple resources need to be managed during periods of scarcity of cognition, computation, bandwidth, electricity, memory capacity, blood sugar, and hydration. WEHST's presence in first-responder work environments encourages ongoing processes of naturally selecting system configurations. Such use patterns force the coexisting paramedics, device modules, and sensors and effectors into a system of co-evolved interactions.[cxii]

In conclusion, WEHST system-level architecture assembles an interoperable[cxiii] suite of modules in real-time into multiple possible wearable system montages which change paramedic and WEHST shape, or morphology, as part of human-based – and situated – computing. Combined paramedic and WEHST morphologies are designed to adapt optimally to numerous external demands. Paramedic and WEHST embodiment can be mutually and autonomously re-shaped in response to external demands which change the morphology. This design applies human-in-the-loop personalization which allows off-the-shelf manufacturing and material technologies to produce a wearable and distributed morphological computing system.

However, as an ongoing design process leveraging the irreducible complexity of the designed teleparamedicine environments, operators, or tools. These findings are relevant to more than this specific design project and are generalizable to those design practices concerned with complexity. Opportunely, all scientific research involves research design, guided by scientific paradigms which are veneers atop the irreducible complexity which is the pulse of design.[cxiv]

6.2 Diagrams - System-level design

The middle part of this chapter conveys the teleparamedicine system-level design through diagrams and tables. My research results at the scale of both teleparamedicine and WEHST are too complex for solely written descriptions or simple figurative illustrations. However, formal visual modeling is too reductive to clearly describe in a single diagram the processuality of and deep entanglement of physiological, technical, and environmental teleparamedicine relationships emerging from WEHST technologies. Nonetheless, several appropriate system-level diagrammatic languages exist which may produce sets of multiple classes of diagrams comprehensively representing the proposed associations among hardware, software, paramedic behavior and physiology, and environments.

The modeling format seeming most compatible with my industrial design project is Systems Modelling Language (SysML).[132] SysML diagrams arise from a visual modeling language oriented toward simplifying complex objects and reducing system-level processes. For several years I have endeavored to apply SysML diagramming practices to the task of integrating ANT, and constructivist and process theory into structure, behavior, requirement, and parameter models of teleparamedicine environments, WEHST hardware and software, and paramedic embodiment.

SysML employs esoteric jargon and specialized tools beyond the ken of neophytes tackling all but the most narrowly bounded and scarcely situated projects. Simply reading SysML diagrams demands an unfeasible degree of expertise. However, SysML is an excellent tool for projects sufficient large and complicated to oblige system

[132] The official site for the international non-profit organization responsible for SysML: http://www.omgsysml.org/

engineering resources. Hence, SysML is an appropriate tool for commercial research and development of WEHST, but unsuited to strict application within this ANT-grounded interdisciplinary dissertation.

While systems modelling language (SysML)syntax has not yet been extended or configured to formally convey ANT associations; it remains a modeling and prototyping medium for specifying manufacturing requirements, software development, performance parameters, and interface refinements. Thus SysML tools offer a formal accounting of the concrete things ANT is concerned with, while remaining inadequately developed for elegantly conveying minutiae of non-local and non-unitary behaviours. Therefore, my 2D design modeling specifications are formatted to general SysML standards, while making concessions for particularities of ANT actants black boxing and translation processes. Taking these liberties with SysML syntax to accommodate ANT does not detract from effectively communicating technical details and intellectual property, and makes models comprehensible and reasonably aesthetic for neophytes.

Table 6.1: WEHST detailed architecture of family of eight subfamilies.

Subfamily	Role
PSYchophysiology	Physiological body signal detecting, monitoring, and limited biofeedback.
	Multiple analog and digital sensor inputs and a patient drive port for electrically grounding the operator.
	Includes biofeedback, peak performance, stress management, and rehabilitation capabilities.
POSition	Location specific sensing of the environment, garment microclimate, and near-body sensing/feedback.
	Does not measure physiological signals *per se* but can be used to detect touch or gesture.
MEDia	Telepresence media production and playback.
	Generally configurable as wearable videoconferencing.
COMmand	A gatekeeper for telepresence, this module controls three-way communication between the remote supervisors, the field operator, and wearable teleparamedicine tools.
	It also sets the balance of the control shared between the supervisor, field operator, and the semi-autonomous human-mediated teleparamedicine system as individual discrete modules or as the multi-agent WEHST system.
	This equates to setting levels of autonomy of operator and wearable system.
PROcessing	Specialized signal processing resources are put into these specific types of modules which include heat dissipation and high power consumption features.
	Specific processing capabilities include compression, signal processing, encryption, types of artificial intelligence, etc…
MEMory	Memory modules are solid-state hard-drives for data storage, cataloging, and retrieval.
	They are needed to buffer telepresence media when recording high-definition (HD) signal, and when telecommunications networks fail.
POWer	Power modules are hot-swappable and stackable batteries allowing the system to be reloaded with batteries without shutting down.
HUB	The HUB is Power/Data transmission module with wired and wireless capabilities.
	The HUB physically integrates disparate modules in order to reduce the power consumed by wireless data transmission.
	The HUB includes an optional electrically isolated output for the PSYchophysiology module.

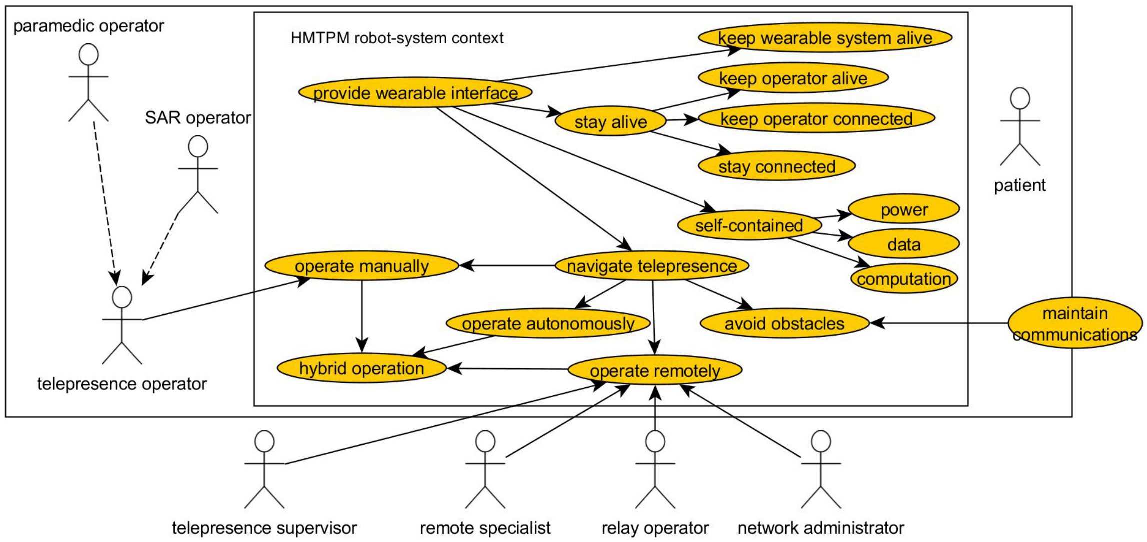

Figure 6.2: Wearable semi-autonomous telepresence system context.

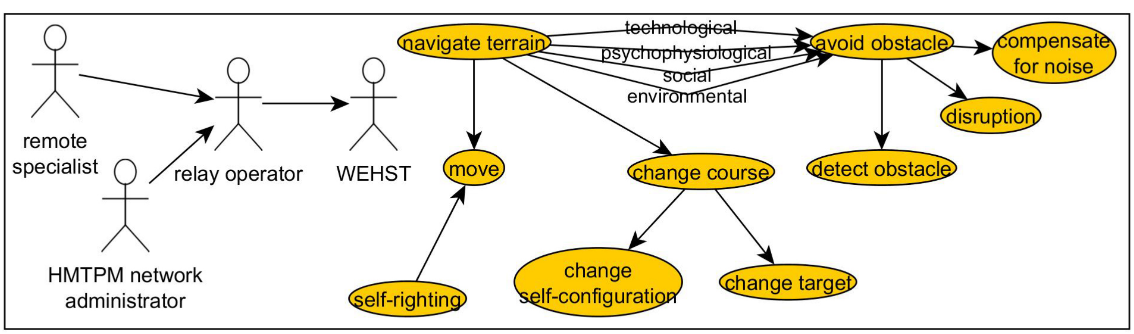

Figure 6.3: WEHST Navigate terrain use case breakdown.

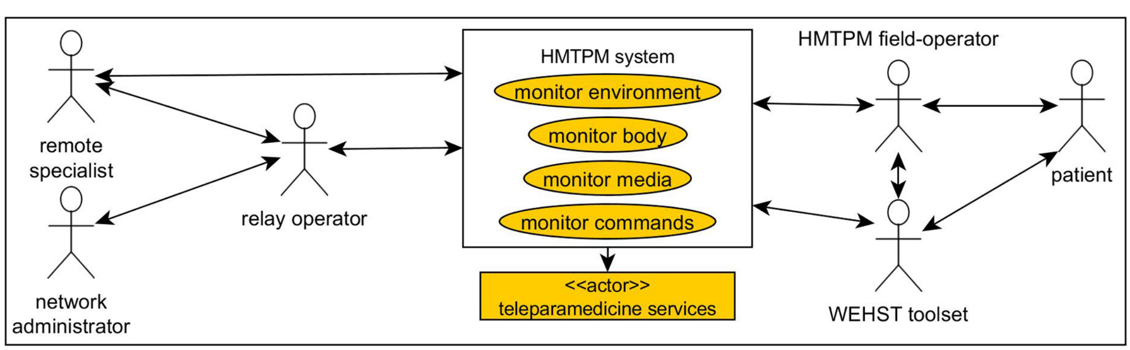

Figure 6.4: Human-mediated teleparamedicine system use case.

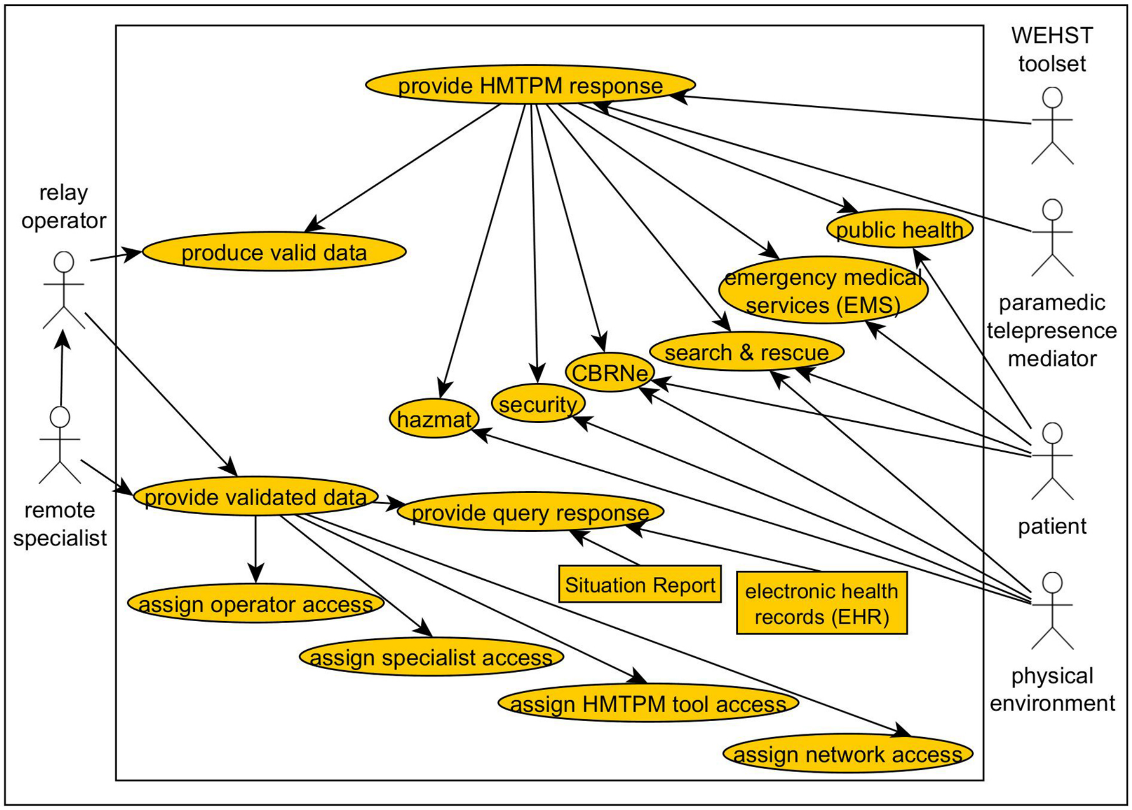

Figure 6.5: Generic human-mediated teleparamedicine enterprise use case.

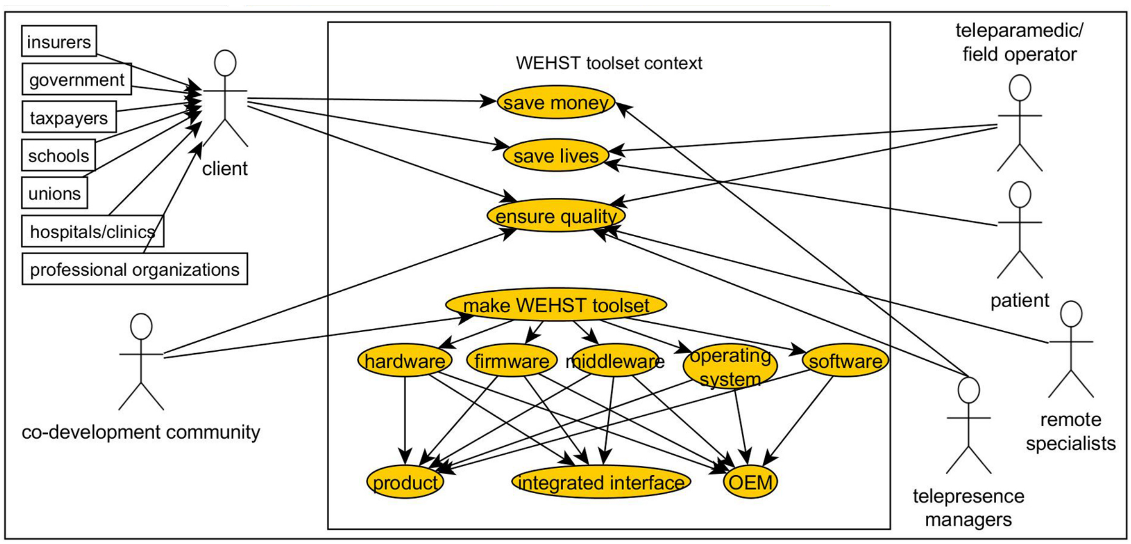

Figure 6.6: Human-mediated teleparamedicine business context – development use-case.

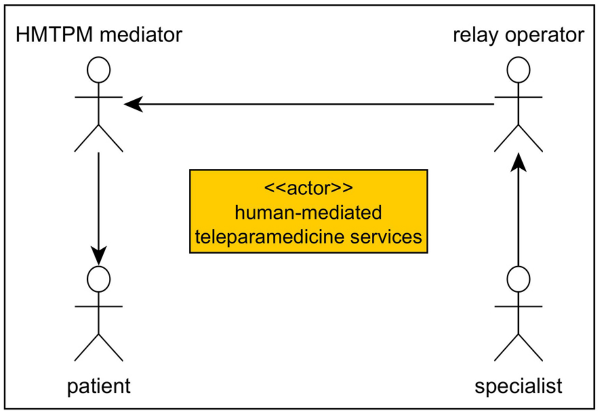

Figure 6.7: Human-mediated teleparamedicine services.

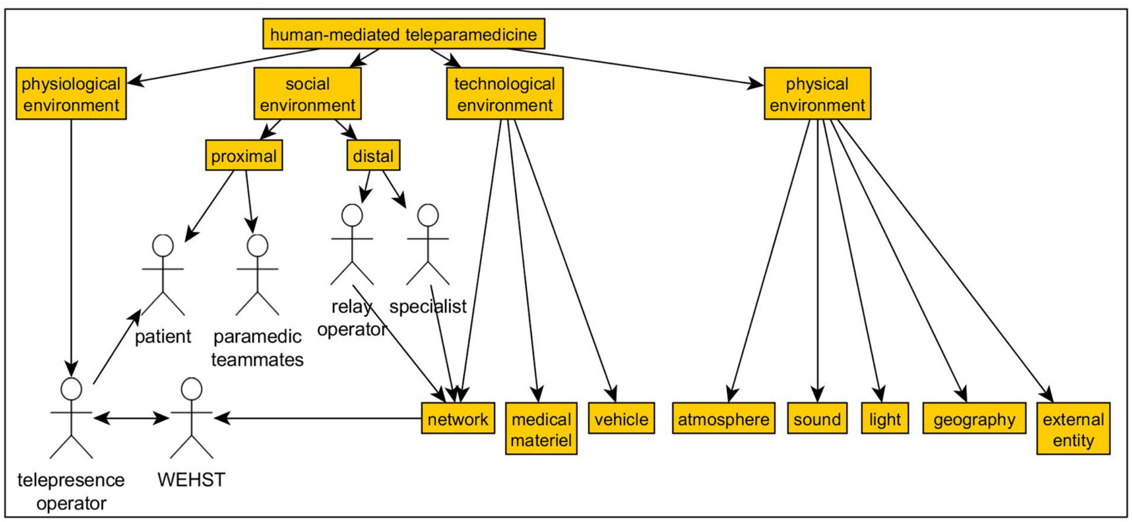

Figure 6.8: Teleparamedicine domain structure.

6.3: Images - Making of the final object

The final part of this chapter is comprised of detailed illustrations corresponding to the physical instantiation of the WEHST toolset.

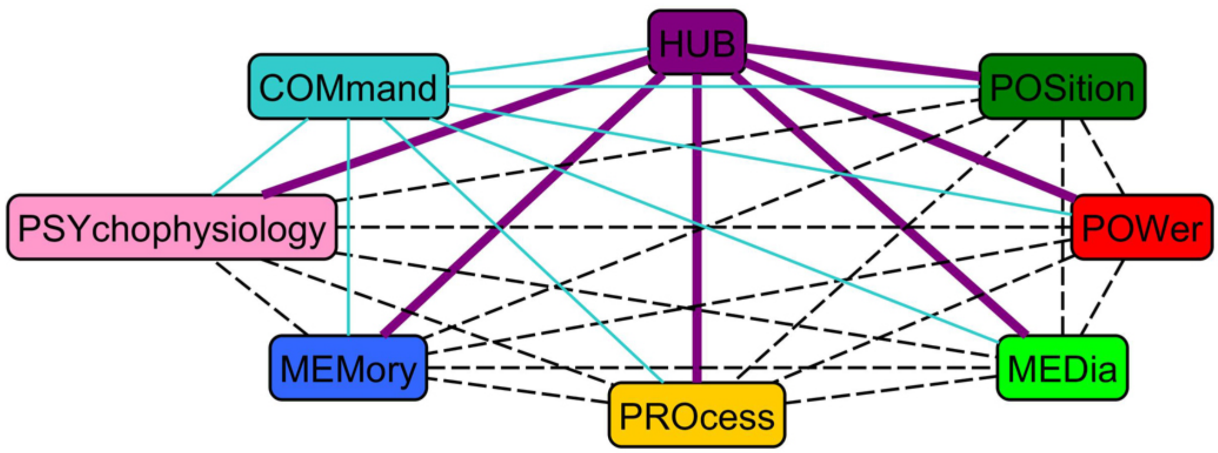

Figure 6.9: Possible interconnections among WEHST modules offer many possible configurations.

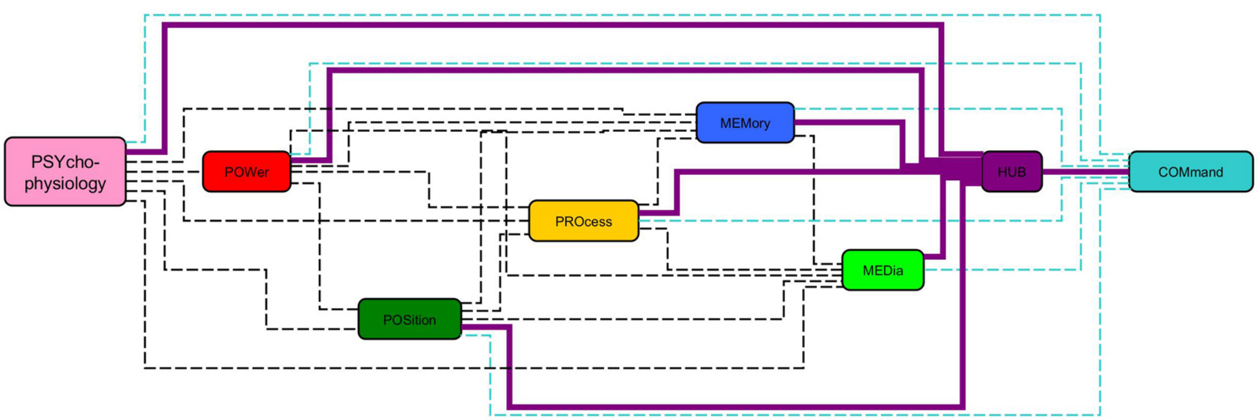

Figure 6.10: These interconnections are mappable onto multiple underlying architectures. For example, connecting communication to psychophysiology.

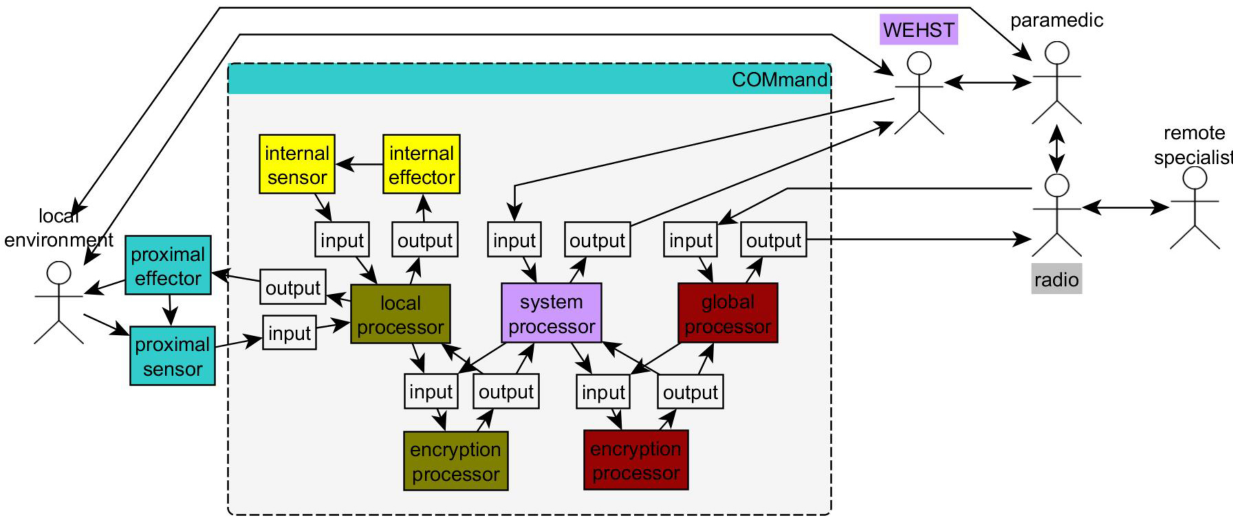

Figure 6.11: COMmand internal architecture of multiple processors and external actors.

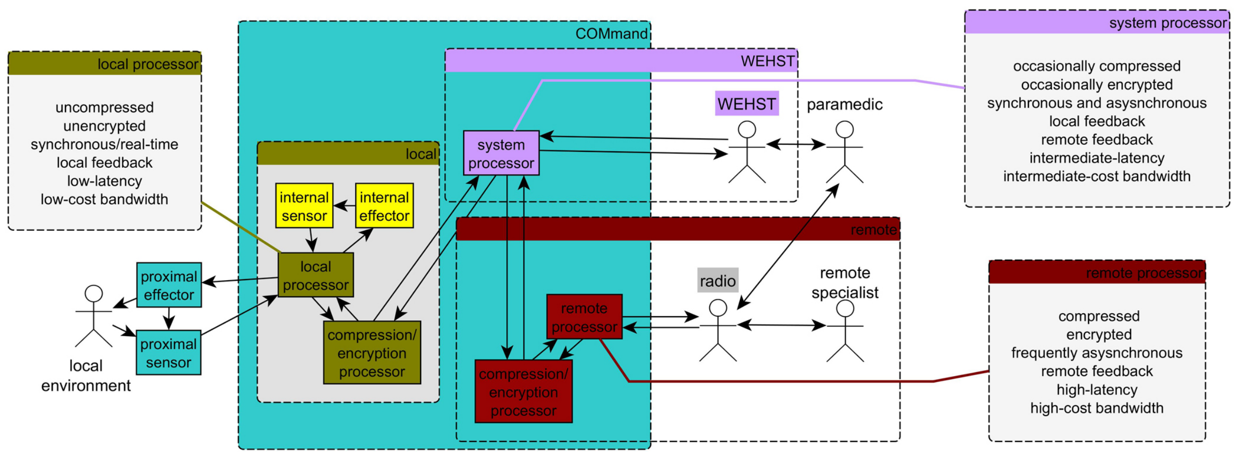

Figure 6.12: The relationships among COMmand internal architecture of multiple processors and with external actors.

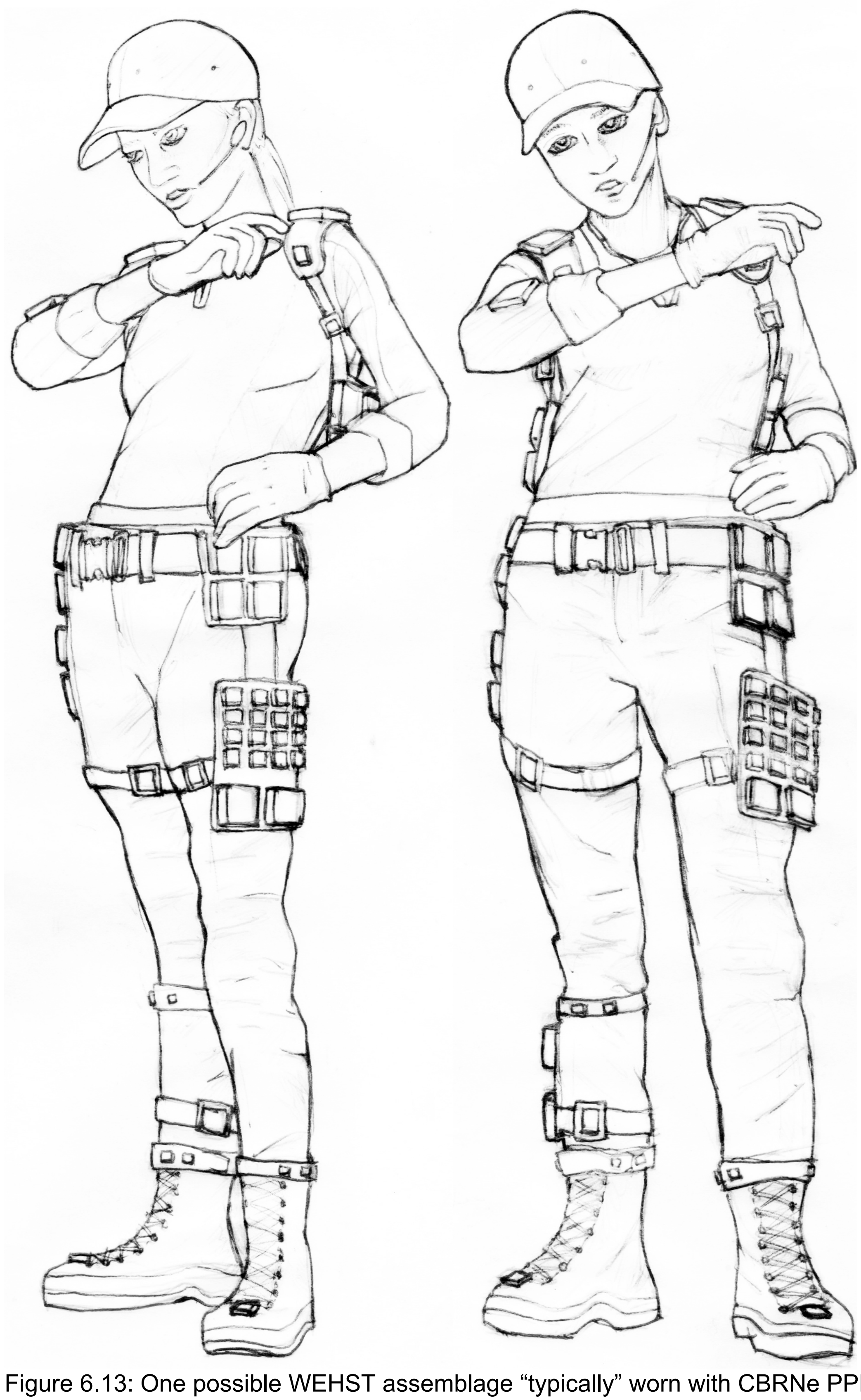
Figure 6.13: One possible WEHST assemblage “typically” worn with CBRNe PPE.

Figure 6.14: Distributing the dozens of WEHST modules around the body retains range of motion inside of CBRNe PPE.

Figure 6.15: Dozens of WEHST modules may be worn on the surface of the personal protective equipment to retain range of motion inside the suit.

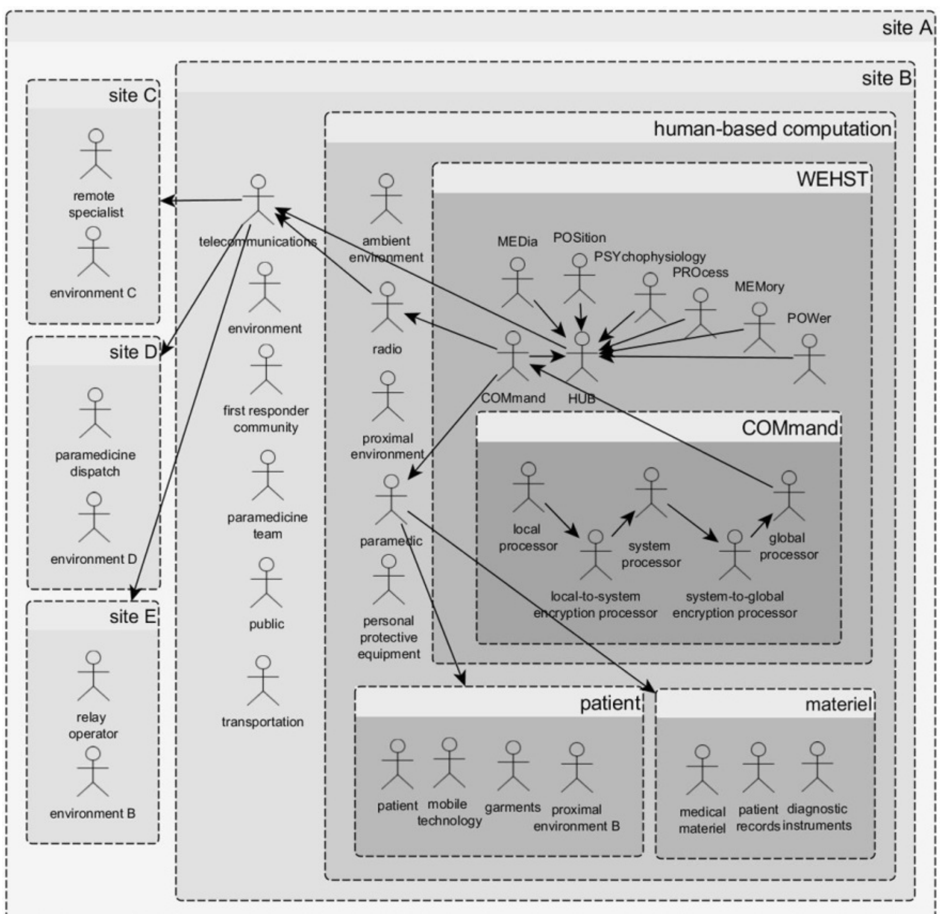

Figure 6.16: Human-mediated teleparamedicine actors are spatially and temporally heterogeneous and may be black boxed at multiple scales.

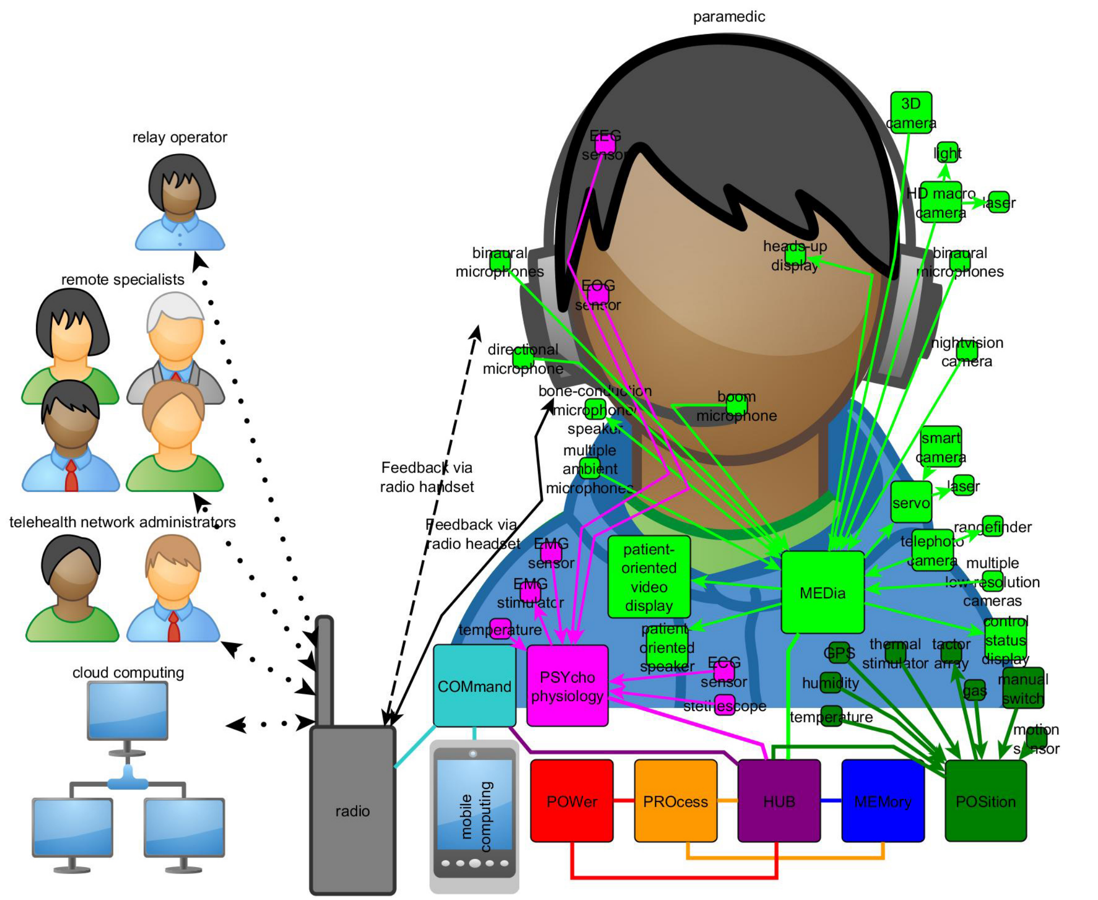

Figure 6.17: A full WEHST assemblage (one of many possibilities) for wide-spectrum human-mediated telepresence.

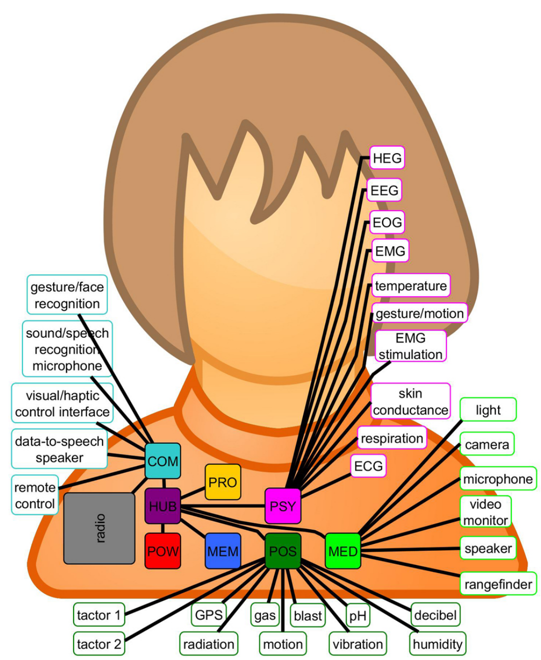

Figure 6.18: A generic full WEHST assemblage for telepresence.

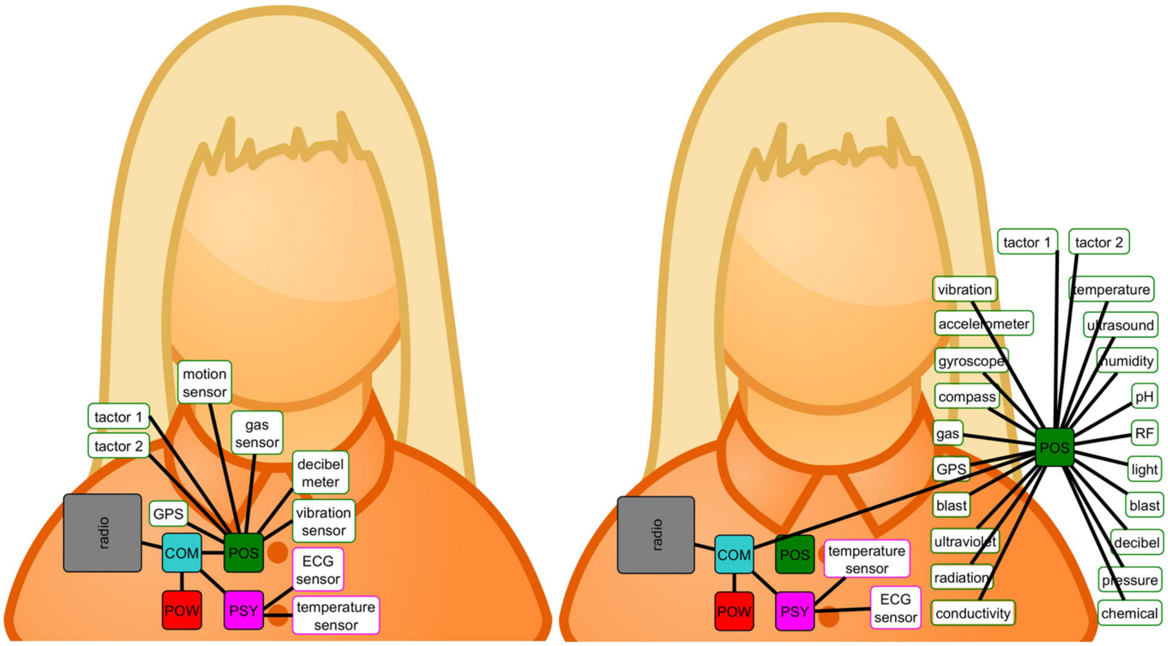

Figure 6.19: Two variants of POSition-biased WEHST assemblages.

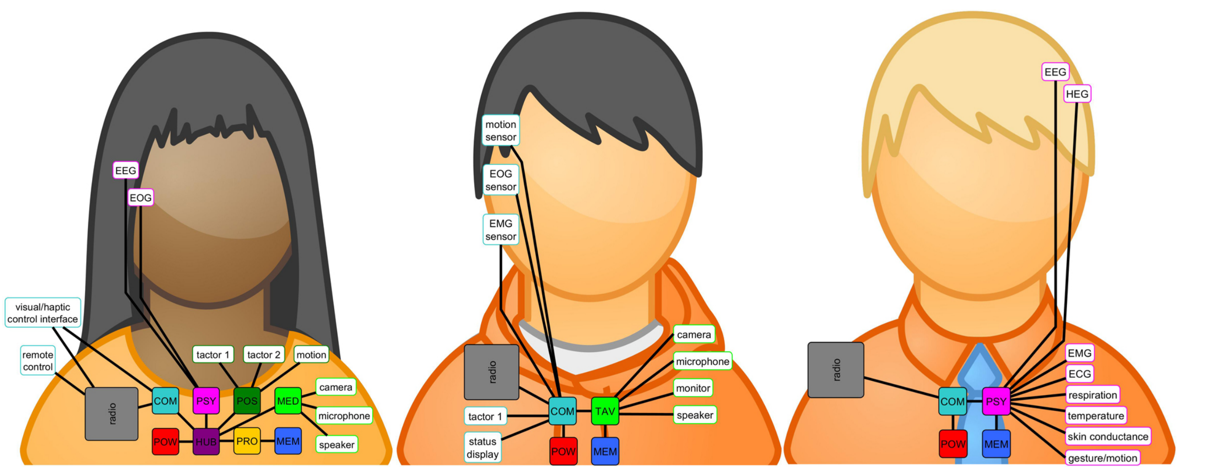

Figure 6.20: Three variants respectively characterizing: high-performance hands-and-voice-free wearable telepresence; bare-bones performance hands-and-voice-free wearable telepresence; and robust PSYchophysiology-based hands-and-voice-free control of radio *and* health monitoring.

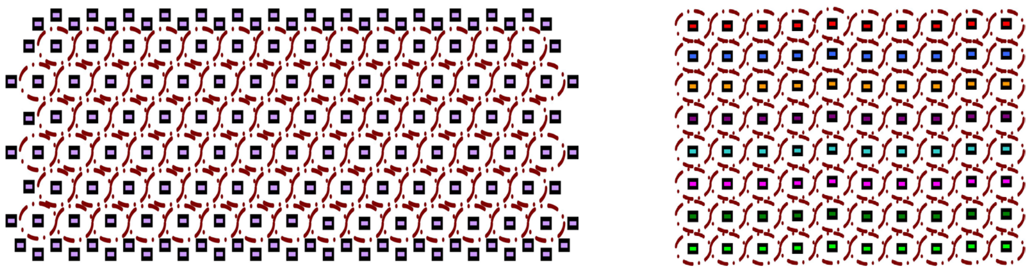

Figure 6.21: The granularity of the “chunks” of electronic computation software and hardware are distributed across on and in textiles woven from conductive and non-conductive fibers. The chunks of computing can be mixed in terms of performance.

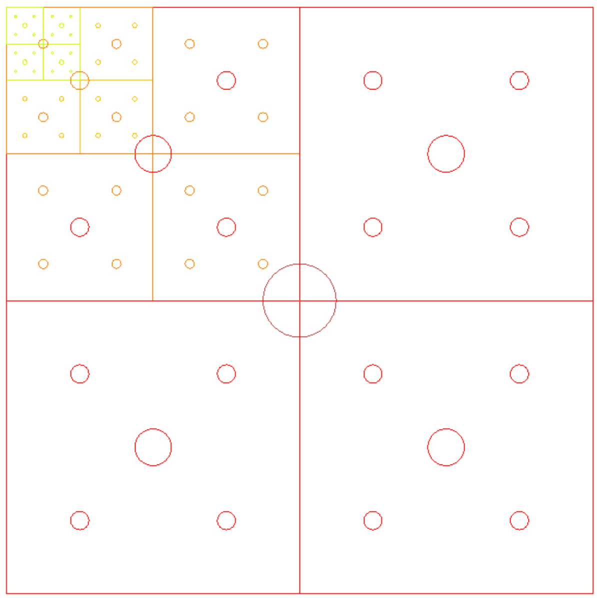

Figure 6.22: The basic overlapping footprints of the modules are aligned as an exponential size scale. This image shows the graduated diameters and positions of the assembly hardware points. These patterns also correspond with possible metal connector pin and socket positions and diameters.

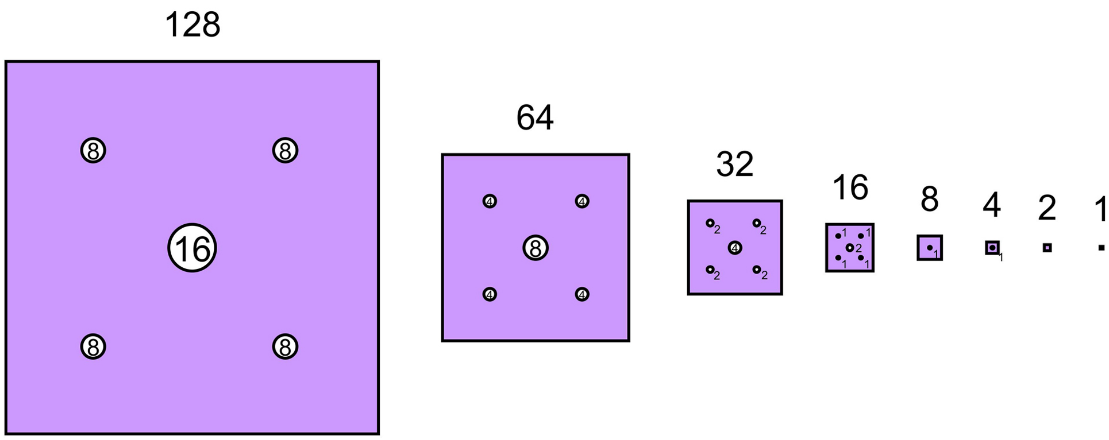

Figure 6.23: An example of one of many possible exponential size scales. All dimensions are in millimeters (mm).

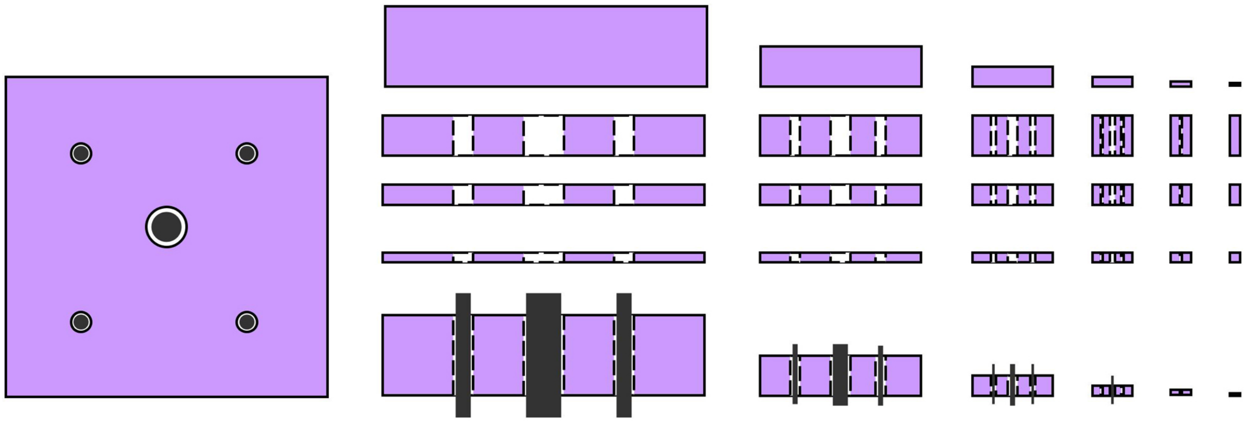

Figure 6.24: An exponentially sized modules showing assembly hardware positions.

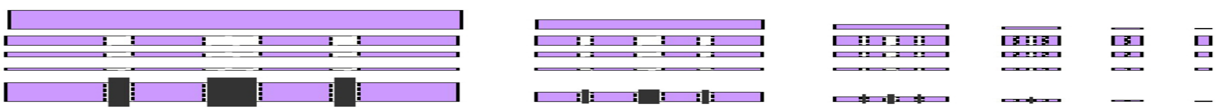

Figure 6.25: A side view shows how textile layers may fit between modules as a supple physical interconnect for data and power.

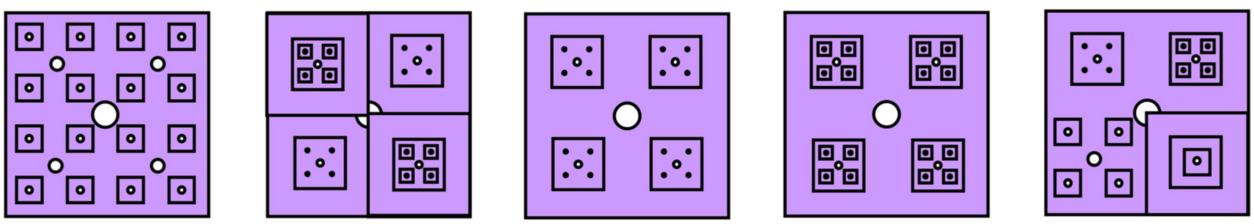

Figure 6.26: A top/bottom view shows how WEHST modules are stackable with pins physically interconnecting data and power.

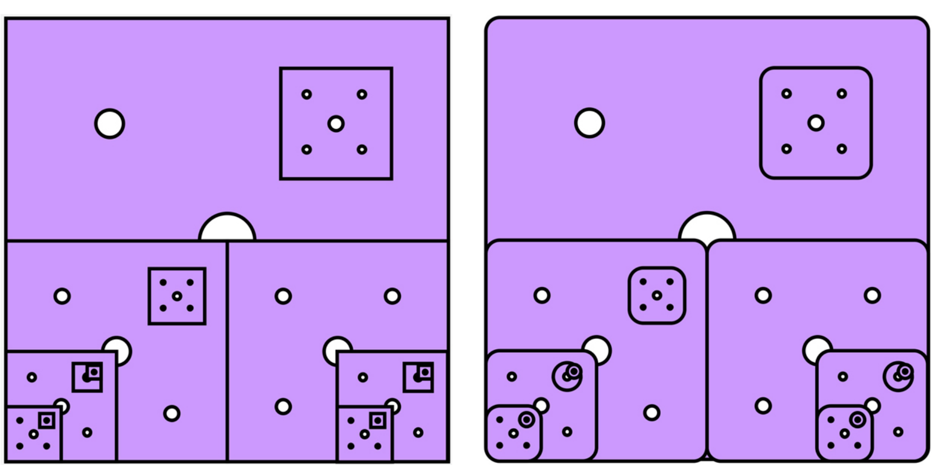

Figure 6.27: A top/bottom view shows how WEHST modules can have many different corner radiuses to improve safety and aesthetics.

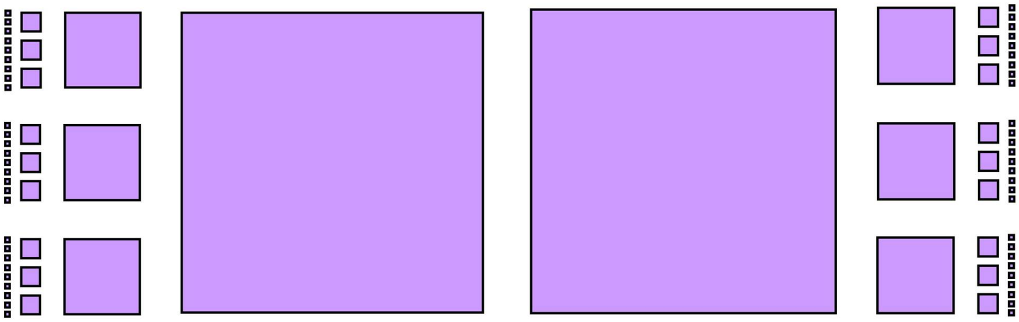

Figure 6.28: A top/bottom view shows how WEHST modules can have many different gradients of size and position.

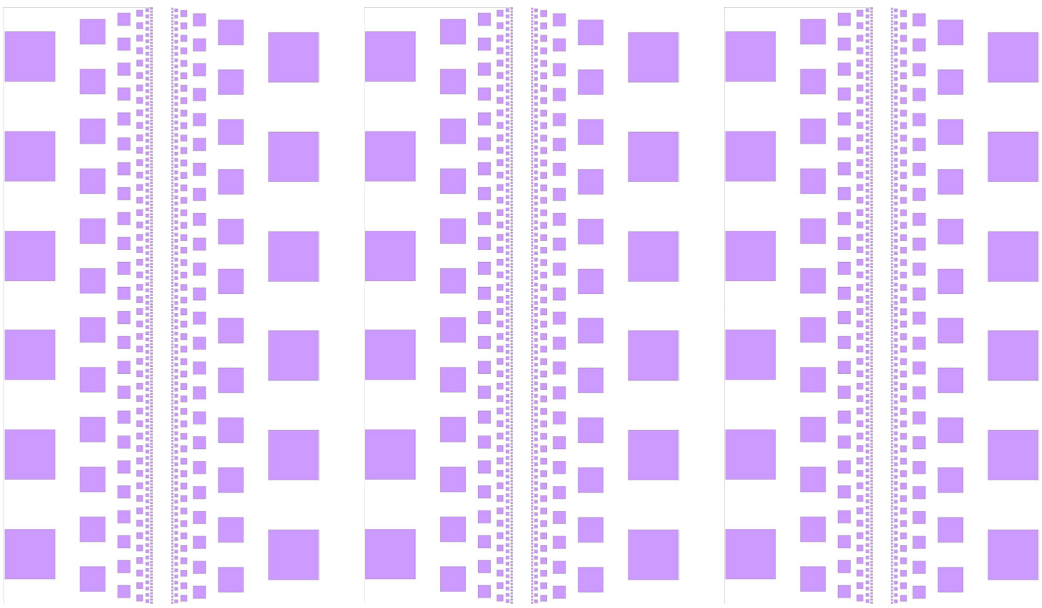

Figure 6.29: A top/bottom view shows how WEHST modules offer many patterns.

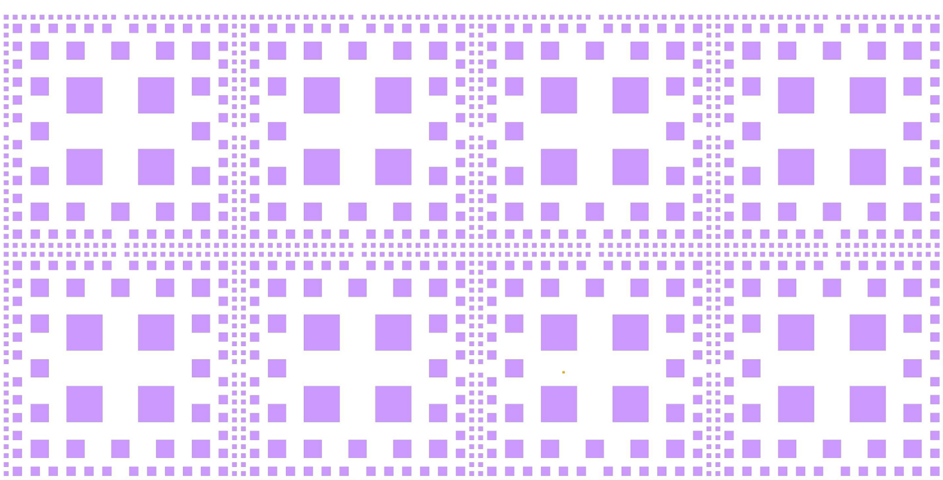

Figure 6.30: WEHST can be assembled into large continuous textiles.

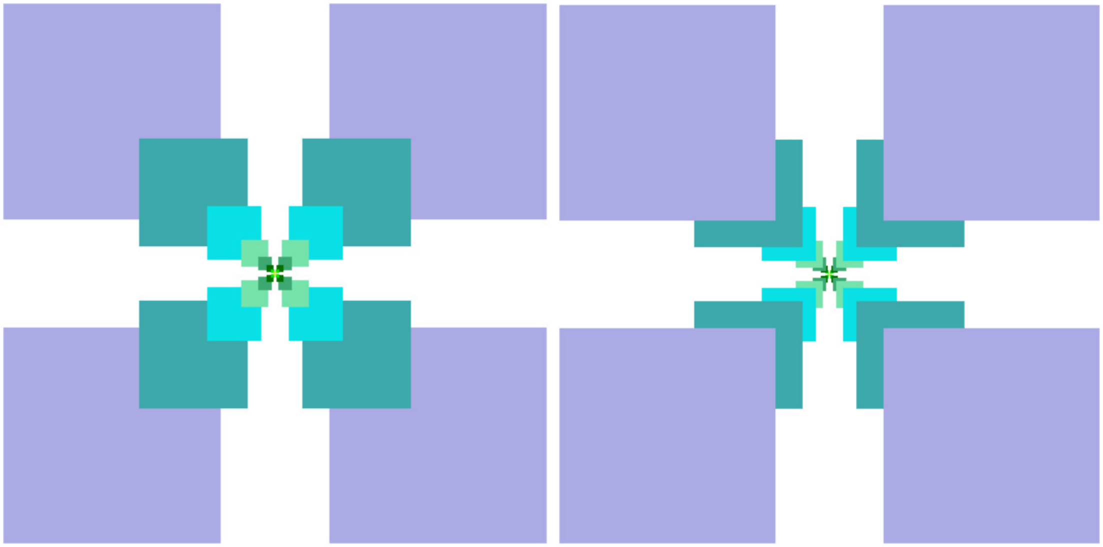

Figure 6.31: Overlap among WEHST modules of all sizes is possible and necessary.

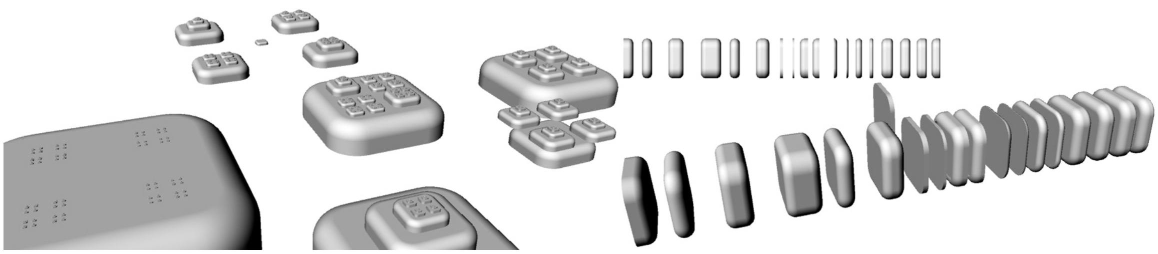

Figure 6.32: WEHST's surfaces may be contoured with radiuses to ensure safety and comfort.

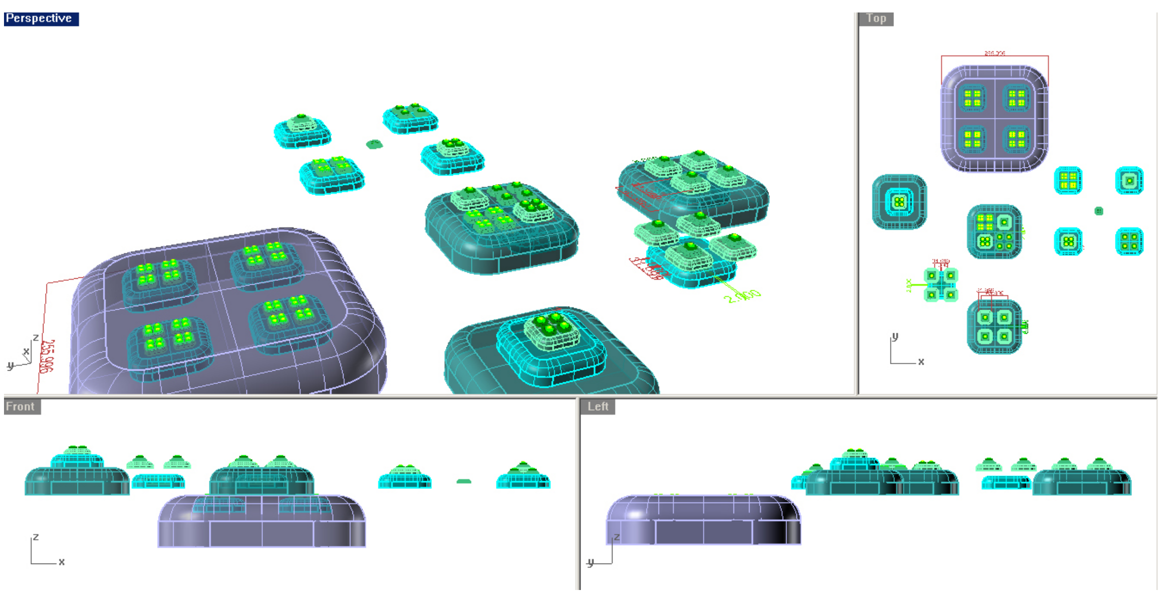

Figure 6.33: Stacking makes many small microclimates in close proximity to the WEHST modules.

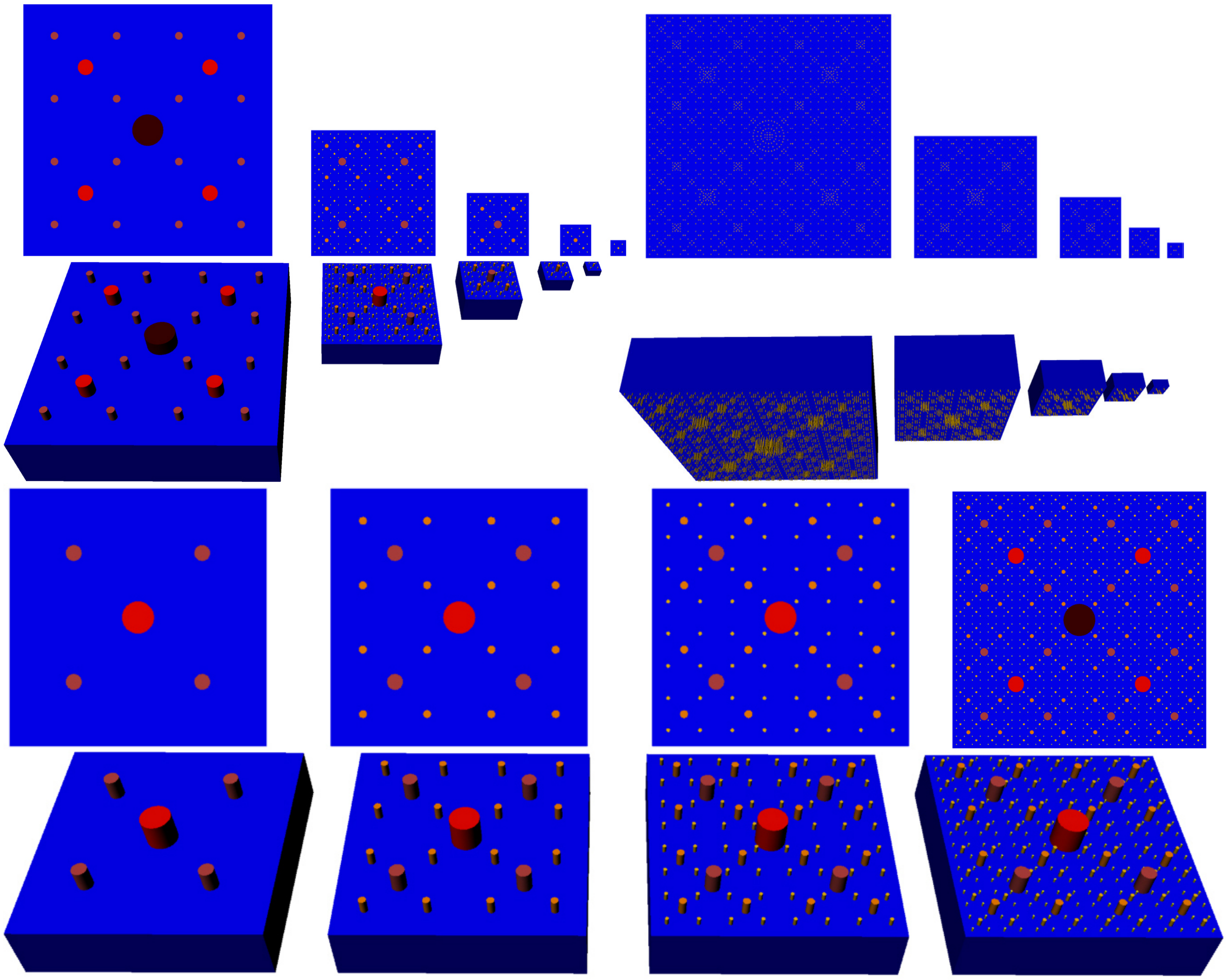

Figure 6.34: Connector pin sizes, shapes, positions, and densities.

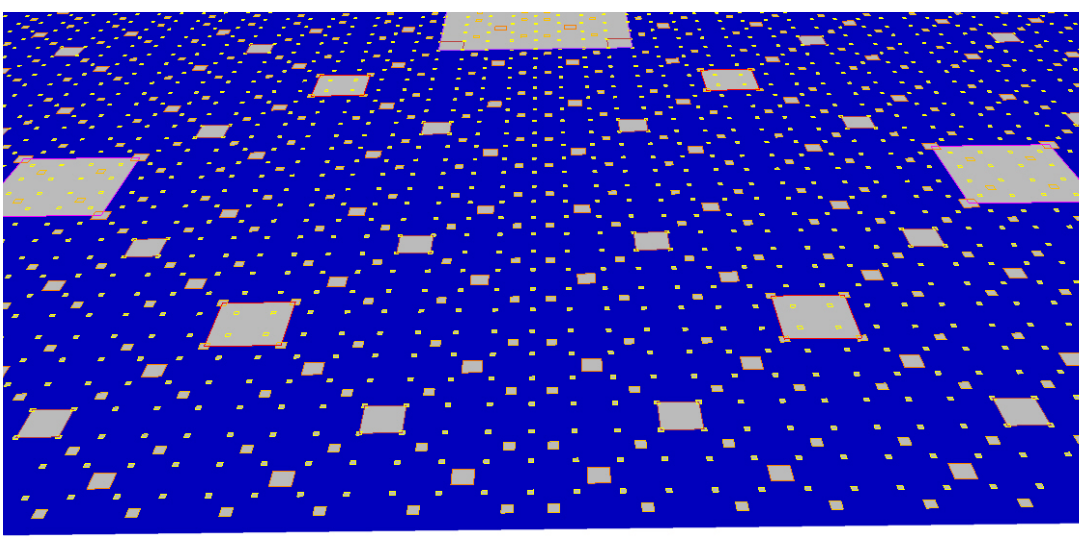

Figure 6.35: Conductive weave structures may form ponts of connection at various depths and positions corresponding to pin lengths and diameters.

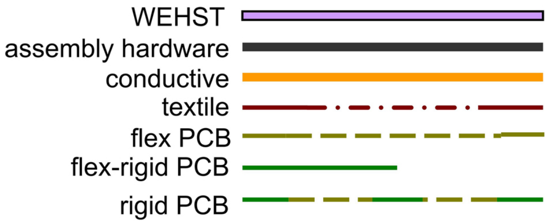

Figure 6.36: Visual key for materials in the following seven images.


Figure 6.37: A generic cross-section showing mixed textile, flexible generic electronics, rigid generic electronics, and WEHST modules.

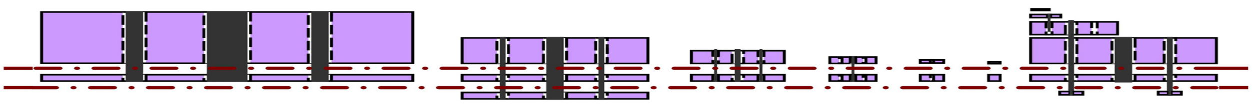
Figure 6.38: A side view showing WEHST stacking and layering with conductive textiles.

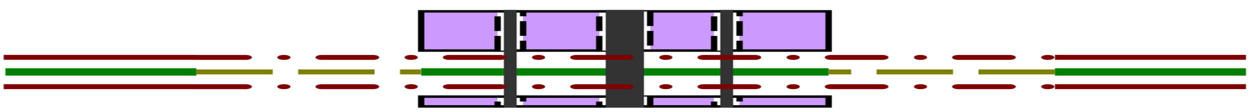
Figure 6.39: A side view showing WEHST stacking and layering with mixed flexible and rigid electronics.

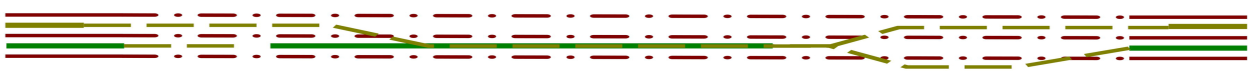
Figure 6.40: Stacking and layering mixed flexible and rigid electronics amid woven and laminated textile structures gives a flexible and robust conductive substrate.

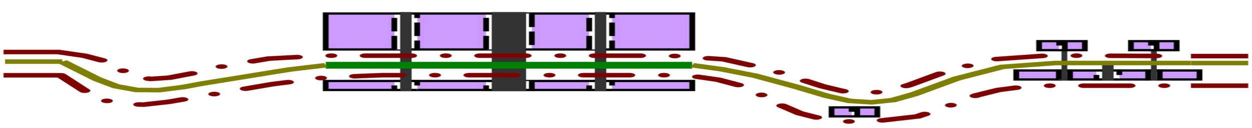
Figure 6.41: WEHST interwoven with flexible and rigid electronics and 3D textile structures makes WEHST assemblages wearable.

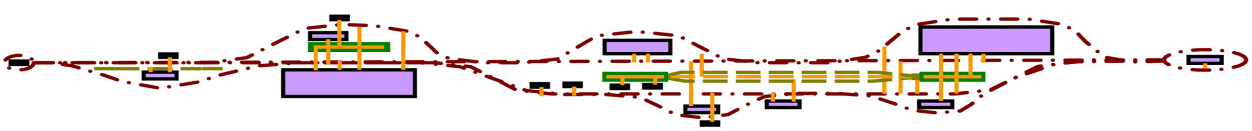
Figure 6.42: WEHST interwoven with electronics and conductive textile may have hundreds of possible electronic interconnection strategies.

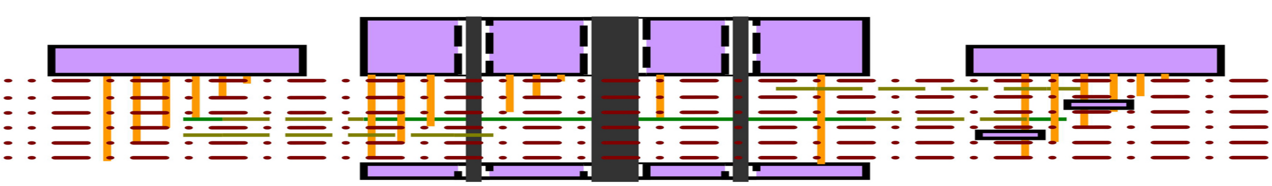
Figure 6.43: WEHST and conductive textiles interconnection strategies benefit from closely controlling connector pin depth and textile connector pad layers.

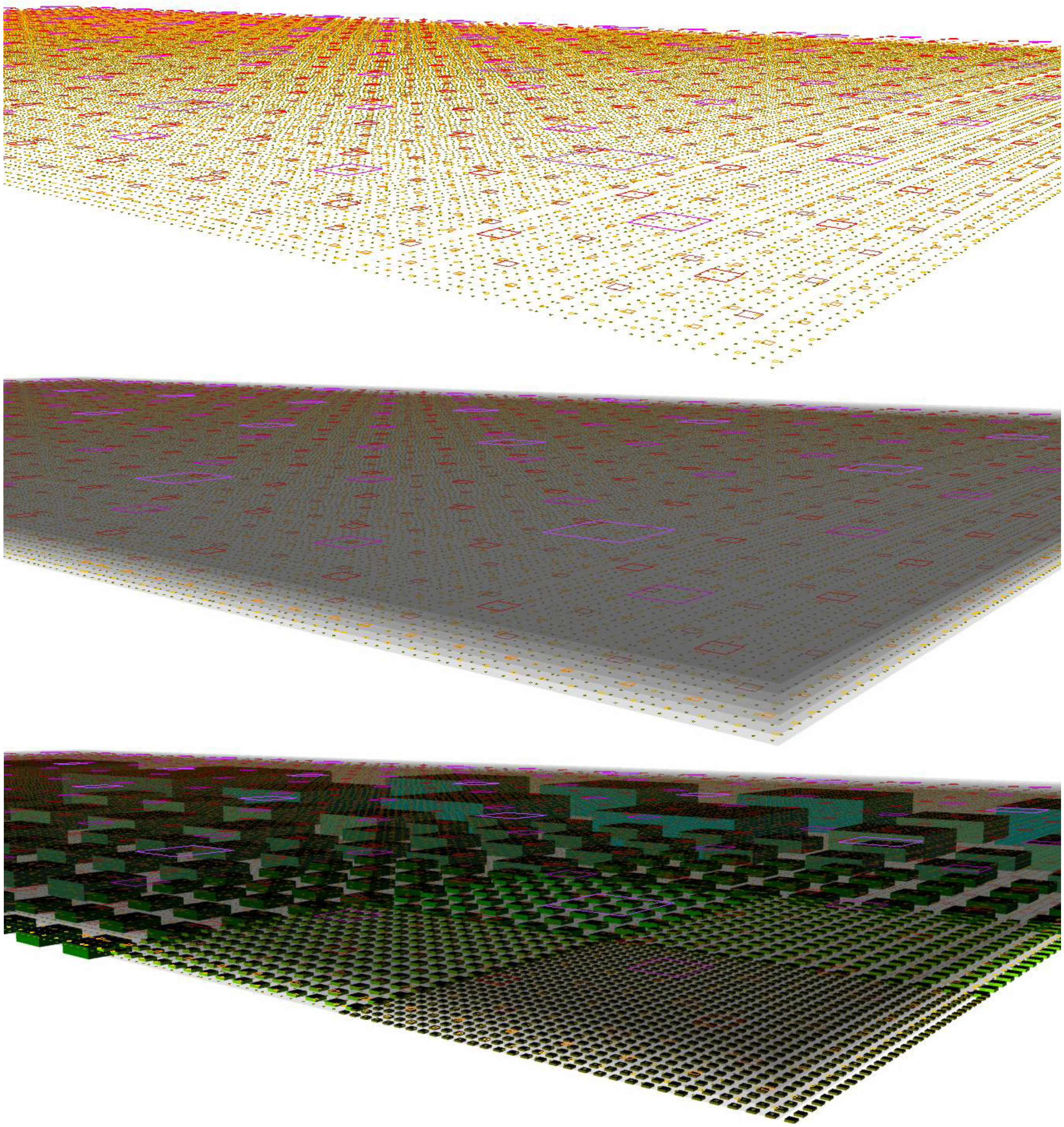

Figure 6.44: Three views showing conductive pad target zones, fabric layers, and WEHST module patterns of gradations.

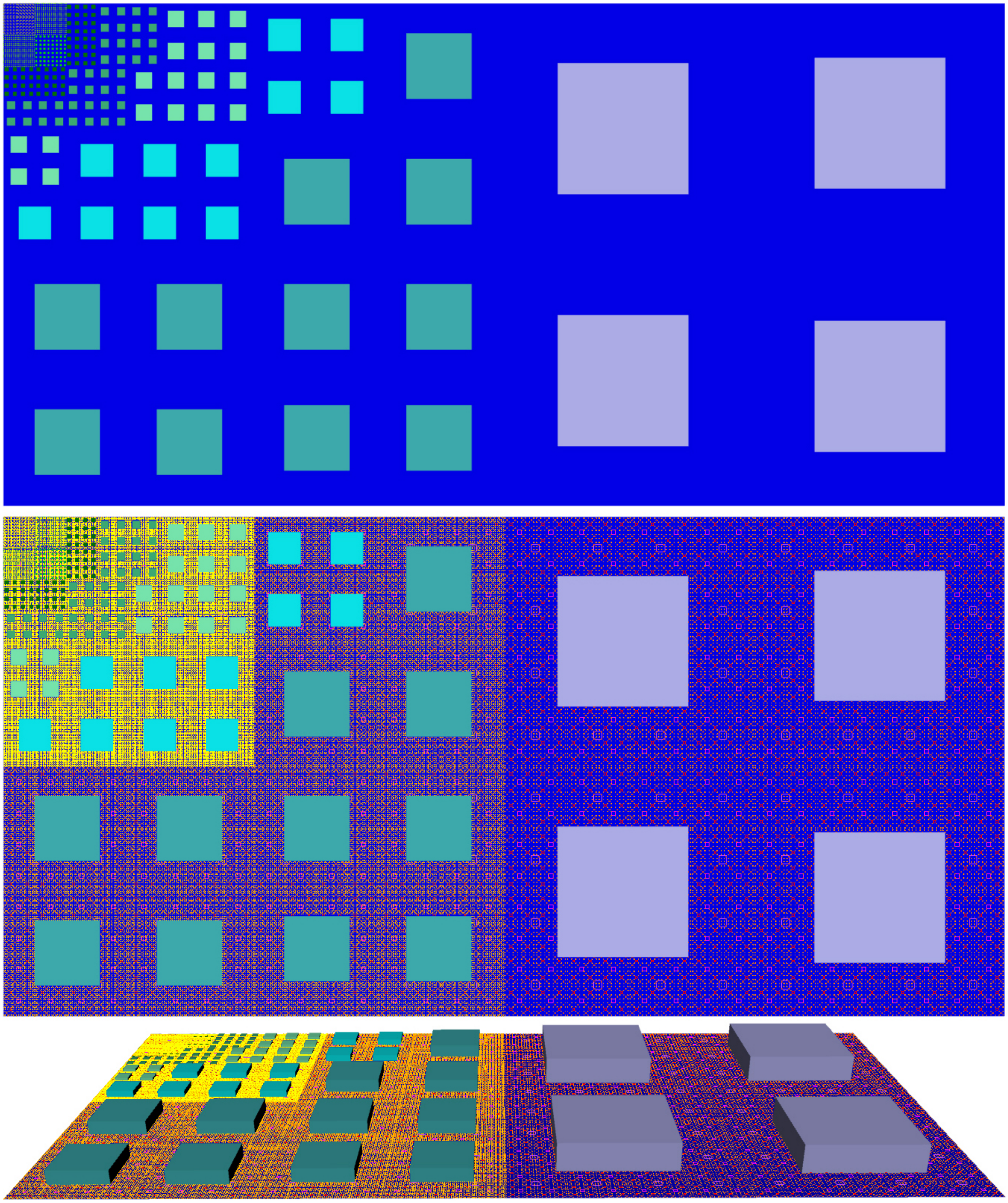

Figure 6.45: Overall positions of WEHST modules relative to conductive pads printed or woven into a textile substrate.

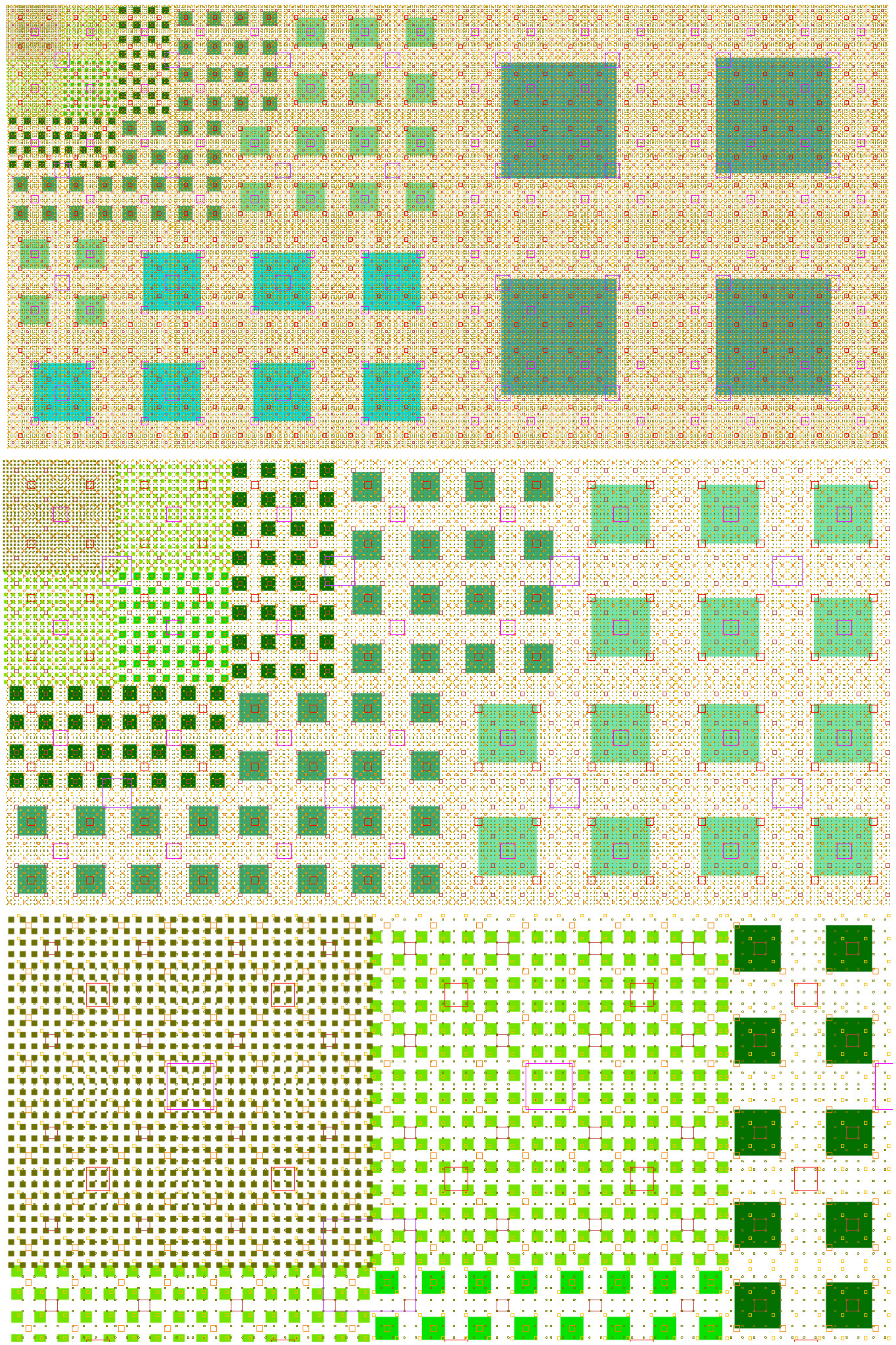

Figure 6.46: Computational textiles deploy WEHST modules at different densities corresponding to patterns in their textile substrate. These three views show the same textile at three levels of zoom.

Figure 6.47: Samples from a 2007-2008 series of manually woven 3D structures appropriate for forming woven electronic features and positioning voids and ribs fitting electronic components.

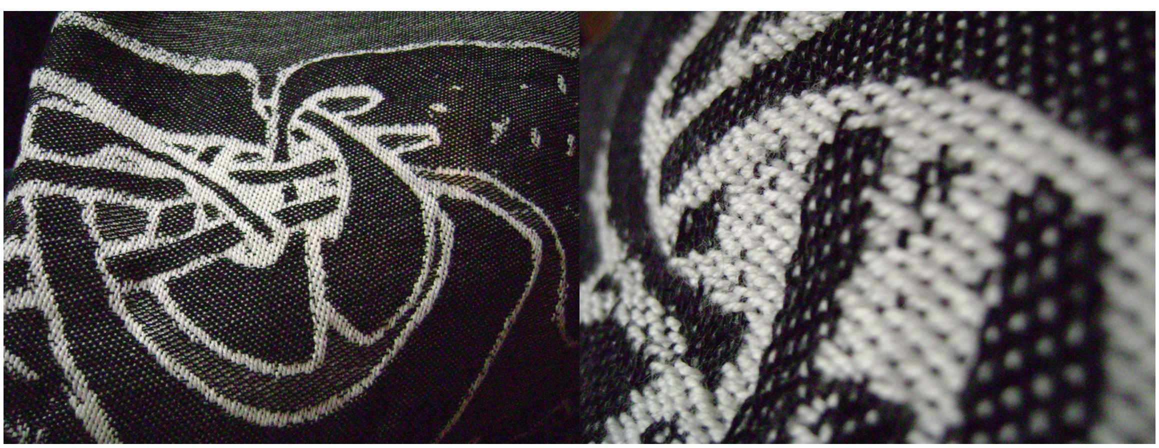

Figure 6.48: Digital Jacquard Loom weaving samples from 2007-2008. This multilayer fabric creates accurate and continuous organically shaped multilayered voids for positioning and securing electronics within textiles.

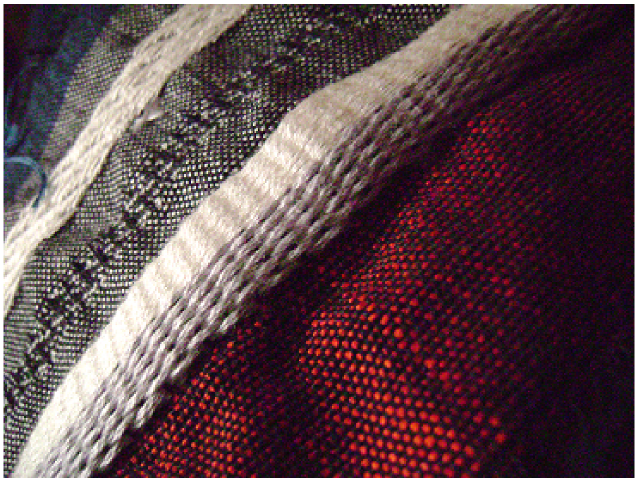
Figure 6.49: The six-layered jacquard weave sample is a bicolored and deeply textured rib left of the red panel.


Figure 6.50: The six-layered jacquard weave sample is split to show six distinct layers.


Figure 6.51: The six-layered jacquard weave sample is split to show how six layered weave structure can be interspersed closely among sharply contrasting weave structures with different numbers of layers, thicknesses, and textures.

Chapter Seven: Reflection and Conclusions

7.1 Reflecting on the whole human-based computation (HBC) industrial design process

> 'Human' requires an extraordinary congeries of partners. Humans, wherever you track them, are products of situated relationalities with organisms, tools, and much else.[133]

This project positions the proposed human-mediated teleparamedicine system as an instance of human-based computation (HBC) design. The main outcome of the research for this dissertation, the WEHST (wearable engine for human-situated telepresence) "system" offers a wearable computing platform technology which appropriately situates multiple nominal artificial intelligences to perform human-based computation. These wearable computing modules enact difficult computational processes by outsourcing to humans those computational steps that humans do better. For example, human-based-computation-capable computers may delegate people to seek patterns too computationally intensive for the computer to recognize. These persons report their results to the computer, which then interprets and acts on this solution.

Cooperative control in most (if not all) human-computer interactions obliges some degree of human-based computation. In the instance of WEHST, paramedics interface with themselves, their teams, technologies at hand, and environments on behalf of wearable computing. Instruments using human-based

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133 Haraway and Gane, o*p cit.* When We Have Never Been Human, What Is to Be Done? 2006. P 147

computation worn by paramedics must be small, efficient, and fast enough to perform tasks otherwise requiring unwearable quantities of computing hardware.

Furthermore, WEHST enables teleparamedicine teams to perform distributed human-based computation. One or more WEHST systems may perform computational processes by outsourcing to groups of human, technical, and ecological actors those computational steps which humans do better. For example, if multiple (networked) paramedic-worn WEHST systems situated in an environment or bridging multiple environments ask the persons wearing them if they perceive parts of a pattern (or patterns) too computationally intensive for the computers to recognize. The paramedic team then reports their results to the multi-agent system of embedded WEHST systems, which then coordinate computation to interpret and act on these multiple solutions.

Design of human-based computation within human-mediated teleparamedicine via WEHST generally applies principles of embodied cognition to make the system configurable to multiple specific use-cases. Embodied cognition leverages the human wearer's perceptual and mobility abilities. Integration of the human-wearer's motor and sensory skills into the system architecture improves WEHST's performance and autonomy in the domain of high-level problem solving, as an instance of Moravec's paradox.[cxv]

WEHST's human-based computation enables learning as an autonomous system not driven by current stimulus alone. Long-term development of its human operator's relationship with the system includes requirement for these semi-autonomous systems to: first, express needs largely in terms of human wearers' embodied perceptual and mobility abilities; and second, to discuss complicated situations decoupled from immediate sensory input, which regard high-level problem-solving requiring relatively little computation.

Embodiment-oriented human-based computation capabilities also position WEHST as a platform technology constituting a real-world-ready semi-autonomous wearable robotic telepresence interface manufacturable from real-world technologies. Robust artificial intelligence may arise in devices with sensory and effector capabilities coupling to their worlds through paramedic's bodies.[134] In these instances, human-based computation tools are human-wearable robotic interfaces, with the WEHST wearing the paramedic's body and the bodies of their proximal teammates (who may or may not also be wearing WEHST systems) which constitute a complimentary proportion of the robots' sensor and effector systems.

The human wearers' body is always *becoming* the coupling with the robots' world. Thus WEHST is an original means of applying technology-embodiment theory, which is a subset of Rodney Brooks' artificial intelligence research, in the development of wearable semi-autonomous telepresence. WEHST is made more effective by minimizing the planning, processing, and perceiving capabilities of the product system. WEHST's intelligence is oriented toward using the least amount of information required for it to produce appropriate behavior. The technology-embodiment theory underpinning WEHST offers guidance for design of autonomous agents capable of achieving strong artificial intelligence by being both embodied and situated. WEHST applies technology-

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[134] Argued by Rodney Brooks, Hans Moravec, and Rolf Pfeifer.

embodiment theory on the premise that this wearable system may achieve robust artificial intelligence by using the paramedic's embodiment and situatedness as artificial intelligence-enhancing human-based computation.

WEHST human-based computation processes combine cognitive processes, natural language, and human metacommunicative competencies to overcome the limitations of contemporary manufacturable technologies. Humans overcome the technical limits of wearable telepresence by: reducing latency and bandwidth bottlenecks; sensor and effector deficits; processor and firmware limits; software and operating system; middleware and networking robustness; and coding data. WEHST is fundamentally contingent on paramedic embodiment to augment technical performance of synchronous and asynchronous telepresence-based training, practice, and research.

> Human Computation necessarily involves a system of humans, which are themselves complex dynamic systems. It is within the structure of this complexity that new capabilities or intelligence may emerge. Human Computation presumes an ecological perspective because participation is situated. Individual cognition and agency are part of an interactive system within which they exhibit reciprocal influence with other agents, both machine and human, as well as the environment.[135]

The paramedic, unable to fully escape their situatedness in telemedical ecologies, are positioned to intermediate and mediate both actants they are copresent with towards elsewhere, and also induce actants elsewhere to be copresent. Extending this symmetry to telemedical ecosystems' non-unitary and non-local processes require paramedics to periodically (and critically) use their cognitive competencies to "project" this whole tangled nexus' of perspectives some distances into the future. Projective

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[135] Michelucci, Pietro. Human Computation: A Manifesto. pp1021-1039. Handbook of Human Computation. Pietro Michelucci Editor. Springer Science+Business Media New York 2013. 1039 pages. P1031

scenario modeling, as opposed to simply observing and responding to emergent scenarios, may require practices of grounding the present in multiple future scenarios simultaneously. Hypothetically, only human actors, and perhaps only rare ones, may effectively “project” scenarios accurately tracking those trajectories most relevant to healthcare. Predictive algorithms are not very robust in real-world team-based practices and require time to evolve. For example, while contemporary computer systems are capable of simple tasks like anticipating trajectories of a thrown ball, these tasks remain very far from human-based understanding of why it was thrown, or how it will be thrown next. Predictive modeling of teleparamedical ecology behavior by individual teleparamedics includes manifold simulations of self, individual and social others, and multiple telemedical ecologies.

Some endogenous ecological variables are determined by teleparamedic actants models, while exogenous variables are assumed to be determined by factors outside of teleparamedics’ models. Several competing future scenarios may evolve in parallel to compensate for teleparamedics' partial and processual knowledge of themselves and of other actants.

> The project of ANT is simply to extend the list and modify the shapes and figures of those assembled as participants and to design a way to make them act as a durable whole.[136]

Reflection on the whole panoply of human-mediated teleparamedicine, WEHST, and COMmand design processes as an instance of human-based computation design is guided by adopting and adapting Latour’s “list of lists” as a checklist to verify the designed objects in and of themselves sustain ANT`s injunctions vis-à-vis associations

[136] Latour*, op. cit.* Reassembling the Social. 2005. P72

amongst themselves, with paramedics, and with designers. Keeping pace with Latour's agenda first extends the list of whom and what participates in teleparamedicine action-at-a-distance; and second, uses those lists produced to set the scope of design as a term growing in "comprehension" and "extension."[137]

ANT generalized symmetry reinforces my cooperative conception of design discipline whereby designers are among a wide range of stakeholders; designers as stakeholders are especially distinct in my chosen instance of industrial design where specifically, the WEHST system (also a co-design participant) being designed perform as a design research instruments and shape research design. ANT symmetry is also instructive for approaching multiple scales of system-level specification as instances of industrial design. Design's flowering scope increasingly introduces system-level scalability processes of association paramount for early adoption and sustained growth by individuals, teams, and institutions. Scalability is perhaps WEHST's most acute concern. The COMmand module stands in here for the greater WEHST product system. COMmand is a perspective, inasmuch a product, giving a narrower, still concrete, design instance to inscribe ANT conformation upon. COMmand is the WEHST subset that traces the formation of groups, maps controversies over agency, makes an object's activity easily visible, and deploys matters of concern.

7.11 COMmand traces the formation of groups

ANT furnishes a basis for reflection on the whole human-based computation industrial design process. In particular I refer to Latour's series of lists from

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[137] Latour, o*p cit.* A Cautious Prometheus? 2008 P2

Reassembling the Social. The first list – in order they appear in *Reassembling the Social* – is "a list of traces left by the formation of groups." I consider this list in terms of administrative scalability[cxvi] relative to COMmand communication capabilities. First, spokespersons are part of group formation, described by Latour as "a rather large retinue of group makers, group talkers, and group holders"[138] who talk. COMmand positioned on one body or on many, produces a continuous log of talking, even non-radio chatter, all traceable in time and place. The log may include who is talking, what they're saying, when they say it, and who may be listening. COMmand itself also talks and makes groups, assembles groups of bodily sites and sensor/effectors, and aligns both WEHST's parts and wider teleparamedicine teams.

Second, anti-groups are mapped counter to groups defined by teleparamedicine administration. COMmand logs general activity and tracks groups' efforts to exclude each other by defining scopes of practice. The numerous first-response trades and members, patients, and families, multiple transportation technologies, and environments are mappable. Tracking these actants is in terms of where, when, and how they constitute themselves as groups. Furthermore, communication with in-group and out-group members is traceable.

Third, resources are mobilized to make group boundaries more durable. COMmand logs tele-communications activity as data and metadata about radio use. Practices generate computable signals when turning radios on or off, changing channels, adjusting volume, shifting loci of control proximal/distal/autonomous, or

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[138] Latour, o*p. cit.* Reassembling the Social. 2007 P32

downloading electronic health records (EHR's). Computable behaviours also include calling on and calling in new local and remote resources.

Fourth and finally, when social-science professionals and material are mobilized, COMmand's interoperability with first-responders – and especially with telecommunication equipment – permits researchers and administrators to share a distributed system. COMmand offers a single platform for conducting social-science research within qualitative and quantitative investigations by looking at aspects of communication patterns.

7.12 COMmand maps controversies over agency

A second list supporting reflection on the whole human-based computation industrial design process is Latour's "list to map out controversies over agency" which defines features considered here in terms of relevance to functional scalability[cxvii] of COMmand human-based computation communication capabilities. Functional scalability is considered here as the ability to add new actors to teleparamedicine networks with minimal effort; while maintaining or improving the core teleparamedicine system functions.

First, COMmand maps out controversial accounts of agencies doing something detectable. COMmand makes loci of non-local and non-unitary actors by distributing and hybridizing control among teleparamedicine actants. COMmand positioned on one body, and more-so on several bodies, correlates changes in networks with actions taken. COMmand produces multiple competing accounts of its networks' transformation.

COMmand enables changes in networks' with long-baseline trials and fine-grained tracing of teleparamedicine as human-based computation choreographies. Agencies are then given a figure.

Second, Latour's "figuration" spans from abstractly idiomorphic actants toward technomorphic, biomorphic, and concretely anthropomorphic actants driven by partially apprehended and compound narratives. COMmand is a recording device. Functionally equivalent to a listening station, it records and describes[139] diverse and widely deployed actants for whom it is counterproductive (and risky) to filter out the voices of interlopers or new additions to the teleparamedicine chorus.

Thirdly, Latour's "controversies over agencies" map oppositions between competing agencies in the form of a continuously appended list of legitimate and illegitimate agencies. Legitimation processes are conducted among, and by, networks of study participants. Inclusion and exclusion of agencies is reflected in COMmand's capabilities to generate highly contextual, contingent, and continuously updated vocabularies. Practice-grounded languages account for agencies moving, arriving, and compounding in teleparamedicine network "world-making activities" that are complex and fast enough to oblige a continually renewed vocabulary to account for fluctuating rosters of agencies.

Fourth, and finally, explicit theories of action proposed by actors explain how agency effects play out among teleparamedicine fluctuations and perturbations shifting

[139] Latour*, op. cit.* Reassembling the Social. 2005. P55

"the range of mediators one is able to deploy".[140] Actors toggling between mediator and intermediary states require a renewed theory of action each time the network fluctuates. COMmand is considered as research matériel continuously adding and subtracting actors who change how wider network function changes. Actors added are concerned with their contribution to how other actors behave.

7.13 COMmand makes an object's activity easily visible

A third list grounding reflection on the whole human-based computation industrial design process is Latour's "list of situations where an object's activity is made easily visible" which supports design for load scalability.[cxviii]Rooted in ANT's "new definition of social as a fluid visible *only* when new associations are being made," the applicability of this list hinges on objects being often made intermediaries through association with humans.

Latour's first injunction is "to study innovations in the artisan's workshop," wherein COMmand documentation abounds and compounds. COMmand is a confluence of disciplines, trades, industries, and prototypes all concerned with COMmand as a documentation platform. COMmand is a hands-voice-free control interface for audiovisual media production, storage, review, analysis and transmission.

Second, Latour identifies objects becoming increasingly visible when "approached by users rendered ignorant and clumsy by distance." COMmand meters

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[140] *Idid.* P58

and modulates the rhythm or tempo of telepresence across time, space, skills, language, culture, class, gender, or species. Paramedics undergoing irregular or novel changes experience COMmand rapidly blinking in and out of their perceptual threshold. COMmand is a management tool for multiple layers of media, and requires the paramedic to periodically reset its span of control across multiple devices uploading and downloading media.

The third occasion is “accidents, breakdowns and strikes” shifting intermediaries to mediators. COMmand is aimed at insertion into such sites, and to embrace its own inevitable normal failures in the line of duty. Tracking its own dissolution in frontline deployment is in part enabled by self-healing architecture with modular, scalable, adaptive approaches. COMmand breakdowns may be spectacular or innocuous. Transitory interruptions or catastrophic collapses may often arise from, or are ameliorated by, management of signal bandwidth and security via on-the-body signal compression and encryption.

The fourth occasion is when objects properly vanish. Documentation permits artificial accounts of objects’ perennially problematic provenance. COMmand always accounts for teleparamedicine networks emergence through synchronous, but more often asynchronous, documentation. COMmand coordinates and tags multiple channels of media so networks may be reconstructed and refigured now, 10 seconds in the future, or by researchers ten or 100 years distant.

Fifth and lastly, fictions and thought experiments reveal connections by re-figuring objects on the fluid platform of human imagination. COMmand is a tool for paramedic self-reporting from the teleparamedicine vanguard; whereupon taxonomies break down and paramedic bodies are politicized as contested resources. Paramedics are pitted against COMmand when paramedics voluntarily and involuntarily modulate their own body signals and speech to subvert, resist, or evade various actants political pressures. Paramedic and COMmand also are tasked with describing their intimate connection, which obliges creative expression and discretion in self-reportage by all parties.

7.14 COMmand deploys matters of concern

A fourth list giving a basis for reflection on the whole human-based computation industrial design process is Latour's "list to help deploy matters of concern." This list grounds my approach of designer and designee's embodiment as global, distributed, positional, mobile, and scalable.[cxix] While telecommunication extends the vertical reach of top-down command-and-control style surveillance of paramedics, contemporary trends towards guideline-based paramedicine are horizontal. As surveillance flattens, sousveillance and equiveillance toolsets emerge, giving paramedics means to subvert, resist, and evade authority by *becoming* positioned *among* authorities.[cxx]

Scaling up from centralized to distributed paramedical care and control is via COMmand capabilities for multimodal mapping and tracking of mobile paramedic's positions.[141] Scientific concerns include entering into ecologically relevant design processes building innovations in the interest of science processes. Geographic

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[141] Latour*, op. cit.* Reassembling the Social. 2005. P116-117

scalability encompasses nonlocal scientific concerns in the non-unitary community of highly situated, relentlessly specific, increasingly distributed science labs.

The first “aid to deploy matters of concern” is Latour’s injunction to situate fact-production in sites such as laboratories and in texts where the facts-in-process are assembled. Teleparamedicine repositions COMmand as hub of multimodal gesture sensing and integrating multi-site activity. Predicated on establishing the multiple perspectives and radical contingency of any embodiment, COMmand design proposes a concrete instantiation of a class of devices that “[…] follow facts in the making and to multiply the sites where they have not yet become cold, routine matters of fact.”[142]

Latour’s second means to deploy matters of concern is seeking sites where matters of scientific fact are “fabricated” and are no longer geographically concentrated into laboratories. They are distributed from telerobotic Mars rovers, to implants, to labs-on-a-chip carried, flown, or dropped where “physically traceable”[143] associations of concern to science and technology abound. COMmand, as wearable infrastructure for evidence-based, practice-grounded research design, juxtaposes the bleeding edges of science and technology studies with the newly quotidian intimacy of operating on-the-body. Distributed computing and surveillance of context in/appropriate in/activity applies to paramedics and their materiel. These omissions and commissions include abrupt or gradual behavioural or postural cues indicating fatigue or injuries; indications of physiological states including effects of pharmaceuticals or biofeedback; changes in

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[142] *Ibid.* P118
[143] *Ibid.* P119

environmental conditions influencing human sensory, cognitive, or health performance; and paramedic coupling with their equipment, team, patients, or environment.

The third means to deploy matters of concern is considering experimentation as producing always in-process results – which is contingent on concurrent meta-inquiry into scientific inquiry. Scientific meta-inquiry writ large is a test-bed for ontologies-in-practice by deploying ontology as scientific practices of pursuing entities who are multiple, processual, and in contention. If a thing is an ontological claim, then COMmand is a thing tracing the contours of ontologies-in-practice scalable up to wider and deeper deployments. COMmand as a sensor fusion hub for internal and external sensors offers multiple ontologies. COMmand's concentration on the body creates a platform for detection and on-the-fly cross-correlation of anatomical and physiological systems, microclimates, and ambient and remote environments.

Latour's fourth and last means to deploy matters of concern is considering how realities are things increasingly becoming “the disputed topic of a virtual assembly.” In such assemblies peer-review includes participation by actants in legal, political, economic, and ecological domains. COMmand stakeholders' concurrent claims to naturalness supersede science's claims to exclusive authority to resolve scientific facts. COMmand, a thing for stabilizing things, stitches together evidence from sensor arrays to feel the radiation, solids, particulates, liquids, gases, and charged particles of chemical-biological-radiological-nuclear-explosive environments. The most cost, size, and weight efficient sensors of this wearable computing platform technology are those embodied human processes deeply situating WEHST's multiple artificial intelligences by performing human-based computation. In summary, COMmand is a wearable engine for human-situated telepresence that traces the formation of groups, maps controversies over agency, makes an object's activity easily visible, and deploys matters of concern

7.2 How my approach contributes to human-based computation industrial design

My approach contributes specifically to human-based computation industrial design processes by emphasizing embodiment of humans and their environments as foundational for system-level design reciprocally enabling computational modularity, scalability, and adaptivity. The central role of embodiment in human-based computation means wearable computing can be stripped down to a minimal set of literal black-boxes which subsume the versatile and graceful human bodies wearing them. Human bodies are always becoming the coupling with a wearable robot's world. Wearable teleparamedicine tools optimize their own planning, processing, and perceptual capabilities through robust artificial intelligence achieved by leveraging paramedics' embodiment and situatedness.[144] This applies technology embodiment theory to semi-autonomous human-wearable robotic interface design; whereby the human body and situation constitute complementary portions of robots' sensor and effector systems.

> Situated knowledges require that the object of knowledge be pictured as an actor and agent, not as a screen or a ground or a resource, never finally as slave to the master that closes off the dialectic in his unique agency and his authorship of "objective" knowledge.[145]

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[144] Argued by Rodney Brooks, Hans Moravec, and Rolf Pfeifer.
[145] Haraway, Donna. Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. Feminist Studies, Vol. 14, No. 3. (Autumn, 1988), pp. 575-599. published by Feminist Studies, Inc.. 1988. P62

Extending organismic metaphors to mobile telehealthcare team composition grows internal architectures of heterogeneous, plural, and compound actors. These multitudes are similar to those human bodies biosymbiotically constituted of microbial microbiomes *and* organs of endogenous cells endosymbiotically[146] co-constituted of organelles and mitochondria. Such biomimetic telehealthcare emerges from, for, and in the forms of its complex ecological provenance. Haraway proposes a similar political and historical contingency constituted by organisms that are, "...an object of knowledge as a system of the production and partition of energy, or as a system of division of labour with executive functions."[147] Transposing Haraway's model of critical biology onto industrial design of actively critical artifactuality may diffract technology outside of categories of: high and low technology, of material or semiotic, or natural and artificial. Emerging classes of critical artifacts, with varying degrees of autonomy and agency, diffract to reveal categories of 'machines' that also inhabit historically and culturally exclusive categories of 'natural' and 'human.'[148]

7.21 COMmand tracks actor-networks and tracks the production of accounts

Latour's series of lists from *Reassembling the Social* is a heuristic description for apprehending how my approach contributes to human-based computation industrial design. Latour's fifth source of uncertainty corresponds with a list of notebooks for both

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[146] Endosymbiotic organisms live within the body or cells of another organism. Symbionts live within the bodies of one another.
[147] Haraway and Gane, *op cit.* When We Have Never Been Human, What Is to Be Done? 2006. P136
[148] Donna Haraway and Lisa Nakamura. Prospects for a Materialist Informatics: An Interview with Donna Haraway. http://www.electronicbookreview.com/thread/technocapitalism/interview Original Post: 08-30-2003

tracking an actor-network and tracking the production of the account. This is relevant to teleparamedicine and COMmand as ANT-oriented research platform, and for *becoming* practical tools for teleparamedicine's concurrent reporting and accounting for bodies in motion among disputed bodily states and territories.

Latour proposes a first notebook as "a log of the inquiry itself" documenting the process of change via field studies. COMmand offers instances of this cross-sensor modality, which is best illustrated by *generation scalability* of psychophysiological detection capabilities. COMmand scales up by driving the design of new generations of[cxxi] hardware, software, firmware, and middleware components interpolating voluntary and involuntary psychophysiological, technical, and environmental signals. Bodies and signals are comparatively context-dependent, adaptable, and plastic. A stable and robust teleparamedicine control-interface voluntarily and involuntarily annotates a stream of media chronicling COMmand and paramedic.

A second notebook specifies multiple and contradictory chronologies and categorical references. Continuously tagging and recirculating information without entirely losing its position. Reconciling this chronological and spatial tracking problem makes COMmand generate and regenerate new generations of components (network actors) on-the-fly by co-configuring and personalizing the control interface. COMmand supports accuracy and speed by testing incremental changes in-use, and compares these to the longer baseline corrected for a wide range of environmental correlates.

A third notebook is for exploratory figuration concurrent with fieldwork, and prior to more rigorous formal writing-up of data collected. COMmand bridges this gap between reportage and inquiry by teleparamedicine actors' active co-participation. Actors code qualitative data streams rich with quantitative correlates. Hybrid accounts of profession-wide experiences and transformations arise as COMmand and paramedic tag and counter-tag shared experiences. For example, while heat stress from chemical-biological-radiological-nuclear-explosive personal protective equipment (CBRNE PPE) is a substantive threat to paramedic wellbeing, heat stress has fuzzy thresholds contingent on individual and contextual factors. Stress *and* stressors variable and ambiguous boundaries merit modulating paramedic-to-COMmand feedback loops and continuously monitoring for telltale stress symptoms.

A fourth notebook is a second experiment embedded in fieldwork working toward understanding feedback effects of study process on participants. This experiment continues past study end dates and emphasizes how research data is perennially negotiated among participants concerned with risks of conducting research. COMmand biofeedback augmentation of coupling with the paramedic sets and maintains peak performance goals, detects and manages psychophysiological stress, and detects and rehabilitates physical injuries. Adding new COMmand software, hardware, firmware, and middleware components leverages human-embodied plasticity. Physiological co-constitution of COMmand control-interface parameters balances reliability against risk of permanent (possibly deleterious) changes in the paramedic, and possibly spreading outside direct paramedic-to-COMmand association.

7.22 COMmand cannot deliver face-to-face interactions

Latour's fifth list "of what face-to-face interactions, [contrary to so many expectations,] cannot possibly deliver" contributes to my approach to human-based computation industrial design by establishing "our own relativistic frame of reference should be indifferent to scale."[149] In terms of COMmand-grounded description of ANT, this correlates loosely with *heterogeneous scalability*[cxxii] across generations of hardware/software/firmware components from different suppliers. Contemporary components are cross-compatible enough to scale up COMmand to a product ecosystem enabling design of the human-based-computation interface for hybrid remote and autonomous control of COMmand *and* paramedic.

"First, no interaction is what could be called isotopic." COMmand-to-paramedic interactions are explicitly nonlocal. Remote specialists and network administrators manipulate COMmand settings and paramedic translation of embodied communication. Formatting in terms of technical and physiological systems includes software, hardware, middleware, and of central and peripheral nervous systems. The COMmand, its sensors, and the radio are distributed around the body. Patients and partners are, even when not present, shaping paramedic and COMmand co-preparation for the next situation. Questions of paramedic physiological signals being *voluntary* is contingent on environment, and shows how paramedics are non-local media, just as COMmand is media signal and carrier *becoming* in transport.

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[149] Latour, o*p. cit.* Reassembling the Social. 2007 P199-200

"Second, no interaction is synchronic." COMmand plus paramedic interactions comprise long and short interactions braided over each other. This means distinctions between voluntary and involuntary paramedic psychophysiological signals are constantly shifting valence as their sequence and tempo shift within the interaction.

"Third, interactions are not synoptic." COMmand interactions are obscured by personalization of parameters to improve performance by reducing the count of distinct actors. Paramedic psychophysiological subsystems, body-environmental sensors, radio states, remote actors, and the COMmand itself are each actively allocated as intermediaries of homeostasis of teleparamedicine speed versus accuracy.

"Fourth, interactions are not homogenous." COMmand-to-paramedic interactions heterogeneously scale multiple distinct agencies via channels circulating aggregates of local and remote agencies. These groups may break down if too much load is given to associations of actors taken as homogenous intermediaries. For example, the distinction between psychophysiological stresses leading to posttraumatic stress disorder (PTSD) versus stressed psychophysiology being induced by posttraumatic stress disorder triggers is only possible if stress disorder prevention, detection, and amelioration strategies take bodily and environmental signals as heterogeneous.[cxxiii]

"Fifth, interactions are not isobaric." Paramedic-to-COMmand interactions balance predictability with adaptability in the face of continuous intrusions into the control equilibrium. Feedback coordinates control of local and remote mediators setting, and intermediaries conveying, goals along a gamut from harm reduction or rehabilitation, to performance augmentation.[cxxiv]

7.3 Conclusions

In its totality – as research project with teleparamedics, as applied thought experiment that mobilizes actor-network-theory, and as the WEHST object-assemblage – this dissertation project makes contributions to fields of including Industrial design, wearable computing, and teleparamedicine.

7.31 Industrial design

Figure 7.1 Teleparamedicine is an open-ended industrial design product category

The industrial design project is limited and delimited to human-mediated teleparamedicine system development to pre-system-engineering and pre-electrical-engineering specifications. This particular mobile multi-agent system (MAS) is described in terms of general hardware, firmware, middleware, and software specifications. The limitations of my research oblige me to account for shortcomings of ANT applied in industrial design practice, and of research-creation and ethnographic techniques in mixed academic and professional settings. My teleparamedicine research and development specialization is also limited by access to research by academic, industry, and government laboratories. The study is delimited by relevance to possible teleparamedicine early-adopters among paramedics in the British Columbia search and rescue and chemical-biological-radiological-nuclear-explosive response communities. I exclude explicitly designing teleparamedicine for mass adoption.[cxxv]

The utility of non-hierarchical topologies for networked teleparamedical tools may be in literal reproduction, in hardware and software, of evolving biological-technological-ecological complexes, modeled on Scott Gilbert's explicitly post-autopoietic concept of "interspecies epigenesis." Endorsed by Haraway as a conceptual alternative to autopoiesis, interspecies epigenesis sustains multiscale processes of spatial and temporal flows of interaction and intra-action as "…reciprocal induction within and between always-in-processes critters".[150]

Teleparamedical tools modeled as not requiring self-referential 'units of differentiation' may be analogs of biology and simulations of subjectivity. Multimodal arrays of transducers, processors, and transponders may be embodied of human, technological, and ecological constituents. These tools are a self-referential category

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[150] Haraway and Gane, o*p cit.* When We Have Never Been Human, What Is to Be Done? 2006. P139

co-constructed within and among paramedics' bodies, distributed network infrastructures, and ambient ecologies. The concept of physical bodies as co-constructed of – and by – material substrates is illustrated by hybrid biological and technological computation practices. Computation emergent from compound networks of mobile telemedical biofeedback is useful for augmented medical communication and intervention. These augmented processes of subjective translocation may demonstrate both medical and metaphysical significance favouring Gilbert's hypothesis that "we were 'never' individuals." [151] Applied in sufficiently complex project-based industrial design research practices, this hypothesis posits products are not singular, coherent, or discrete. Instead, this design inquiry is premised as reflexively problematizing and producing technologies for the modelization of problems.

The product category I propose emerges through inter-actant epigenesis. Such reciprocal induction of units of differentiation is antithetical to conceiving products as discrete commodities with finite scopes. Teleparamedical ecosystems were 'never' objects. Computational textiles may have multiscale interacting and 'intra-acting' processes of co-epigenesis and co-evolution of paramedics' physiology and distributed network infrastructure – and both are situated within teleparamedical ecologies. Teleparamedical ecologies may not be reduced to material cultural embodiments of singular subjects, singular problems, or singular causes. The exceptions may be processes of becoming in relation through relatively low-latency second-order effects.

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[151] Donna Haraway. Encounters with Companion Species: Entangling Dogs, Baboons, Philosophers, and Biologists. Configurations, 2006, 14:97–114 © 2008 by The Johns Hopkins University Press and the Society for Literature and Science. 2006. P113

> The completely self-contained 'individual' is a myth that needs to be replaced with a more flexible description. The symbionts of people are difficult to study for many reasons: complexity of disparate sizes, inability to carry out experiments in human heredity, politics, and social prejudice.[152]

Hypothetical taxonomies of telehealth material embodiments and cultural networks may – with some rigor – categorize people and products as ecological processes. "Ecological actors" may permit industrial-design practices of developing new technologies as emergent telemedical ecosystems. Telemedical models composed of individual social, technological, and biological elements – each with internal adaptation and response – may result from industrial-design ecological modeling introducing new levels of complexity associated with components co-evolving concurrently with the external environment. These up-to-date and dynamic modelling practices support reconceptualising mobile telehealth as inhabiting a 'post-ecology world.' In such instances of categorizing people and products as processes, industrial design may be concurrently situated in reductively industrial and non-reductive 'ecology-in-place' worlds.[153] The decentralization of teleparamedical social and technological medical networks means that teleparamedics' bodily, [cxxvi]

> […] boundaries materialize in social interaction among humans and non- humans, including the machines and other instruments that mediate exchanges at crucial interfaces and that function as delegates for other actors' functions and purposes.[154]

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[152] Margulis and Sagan, *op. cit.* Acquiring Genomes. P19
[153] Haraway and Gane, o*p cit.* When We Have Never Been Human, What Is to Be Done? 2006. P138
[154] Haraway, *op. cit.* The Promises of Monsters. 1992. P297

7.32 Wearable computing

Figure 7.2 Wearable computing distributes control within teams.

The project contributes to the field of wearable computing by demonstrating ANT's impact on design reconciliation of paradoxes of control concurrency among distributed, autonomous, wearer, and remote supervisor control. ANT facilitates articulating my design contribution to understanding naturalistic, reflexive and participatory research. These research modes include practice-led design research, paramedic-mediated self-study via psychophysiological feedback, remote study of reciprocal paramedic-to-WEHST mediation, and paramedic-and-WEHST-mediated field study of situated computation.

WEHST design contributions arose by decomposing wearable computing into eight subsystems generally required for human-mediated telepresence. The first subsystem is a bi-directional telepresence system of visual and audio media tuned and deployed by the paramedic to produce useful and band-width-efficient signals. Second, an extensive suite of environmental sensors are required to detect a spectrum of near-the-body microclimates and ambient environments. Third, adequate psychophysiological sensing capabilities are enable real-time in situ analysis of human performance. Fourth, a gatekeeper subsystem is required to appropriately distribute control between wearer and wearable computer, and to give networked computing resources and administrators a means of remotely operating or reconfiguring the wearable computer.

Fifth and sixth, hot-swappable power and memory modules both allow the size of the montage, or the particular demands on the whole wearable system, to be scaled up or down without compromising mission duration. Seventh, the addition or subtraction of modular processing subsystems changes the intelligence and autonomy of the system by processing and acting on signals received, and by compressing or encrypting its own signals before transmission. Eighth, is a subsystem performing as a hub – linking all other subsystems together and embedding them into a secondary mechanical substrate – making the assemblage wearable.

Meeting these eight requirements provide for a generalized “wearability” by which: unobtrusive body-mounted sensors and devices are positioned at all the body sites necessary; retained in such a way as to maintain telepresence/audio-visual production quality, and bodily and environment signal quality; while permitting bandwidth efficient data collection through synchronous and asynchronous network connectivity and built-in memory and signal processing capacity.

Wearable computing entails inherent self-study capabilities which also encompass the bodies and environments computers are embedded with and in. For example, wearable computing may extend researchers’ abilities to contribute to new technical and theoretical bodies of literature; communicate use-cases and requirements to relevant vendors and representatives; validate and interpret data produced with related classes of devices; and conduct self-study and perform self-teaching with related technologies.[cxxvii]

WEHST configurability permits either rigid or flexible montages meeting varied criteria for regulatory compliance, including conformability to standards for generating, storing, transporting, transmitting, altering, or destroying records in the medical, communications, aerospace, occupational health and safety, and security sectors. Furthermore, WEHST components may be integrated using direct digital manufacturing (such as rapid prototyping) into interactive and intelligent prototypes. As a *Lego*-like research-ready technology platform WEHST's modular and scalable approach offers a foundation for partnerships with researchers requiring novel research instrumentation and commercial product developers.[cxxviii]

7.33 Teleparamedicine

Figure 7.3 Teleparamedicine periodically stabilizes ongoing adaptation processes.

The contribution of industrial designs of human-mediated teleparamedicine, WEHST platform technology, and COMmand device make to the teleparamedicine field is primarily of demonstrating how their similarly distributed macrostructures persist. Stabilization occurs because partially linked sub-structures emerge to enable adaptations to bodily, technological, and environmental perturbations. Telemedicine positions paramedics as the locus of a complex adaptive system[cxxix] emerging from combined control strategies of paramedic autonomy, partly-autonomous WEHST tools based on situated cognition and situated computation (and ecological actants situated) approaches to artificial intelligence, and remote supervision. These multiple control strategies tailor control and feedback signals to give individual users the means to accelerate and reinforce learning of interfaces. Parallel means of control permit control-feedback loops with few false-positives and rapid error detection/correction.[155]

The fluid margins[156] achievable in such proposed mass-manufacturable product systems arise through coupling parallel and serial human-and-computer-mediators – and mediated humans and computers. While teleparamedicine is certainly a semiotic practice of 'virtual' communication, it is a set of practices which, understanding as embodied precludes "the mistake of thinking that intercourse, communication, conversation, semiotic engagement is trope-free or immaterial." [cxxx] [157]

Real-time configuration of WEHST within real use-cases is required for use in many first-response or medical contexts. In such high-risk settings, WEHST enables configuring all aspects of the system architecture (including sensors, processors, power supply, feedback modules, and radios) to comply with the technical, legal, and ethical use case specific performance parameters. WEHST permits the ongoing configurations necessary at the team level. Stakeholder-specific configuration by unions, employers, and regulators fits how and when this equipment will be used, by whom, with what capabilities, and in which settings.

WEHST permits system configuration to occasionally be done in the field by the paramedics themselves under the supervision of remote technical or legal specialists. WEHST is configurable to have multiple types of data-security configurations. Flexible,

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[155] Holland*, op. cit.* Signals and Boundaries. 2012. P7
[156] Haraway, Donna J. A Game of Cat's Cradle: Science Studies, Feminist Theory, Cultural Studies. Configurations Volume 2; Issue 1. 1994. P59
[157] Haraway and Gane, o*p cit.* When We Have Never Been Human, What Is to Be Done? 2006. P152

robust, and rapid encryption and decryption is appropriate for the highly variable types of data collection, transmission, and disclosure required for physiological, environmental and performance data in research, professional practice and training settings. WEHST's performance as a wearable teleparamedicine tool system requires a system design constrained by the ethics of medicine, medical research, and ethnographic research. In summary, WEHST may be configured to operate as an ethical communication tool for paramedics by virtue of its design being constrained by ecological and ethnographic ethics.

7.34 Coda

In conclusion, my general research question of how to design a 'piece' of wearable teleparamedicine instrumentation for paramedics working in hazardous environments is answered by industrial design of a computational-textile-based wearable engine for human-situated telepresence (WEHST). However, to achieve adequate life-saving, pedagogical, and research capabilities, those electronic textiles suitable for wearable computing oblige hybrid computational architectures with digital and analog, human-based, and environmentally situated computing processes. The embodiment of these computational textiles is achieved by weaving tele-operated wearable robotics of – and into – interacting and 'intra-acting' paramedic physiology, telepresence network infrastructures, hazardous teleparamedical ecologies, and flexible fiber-based structures. Distributing the control processes among these actants provides a platform technology improving telepresence by increasing the number, rate, and sensitivity of linkages among operators, radios, and environments.

Subsidiary questions of what would this ‘object’ be are replied to as mobile cyber-physical system designs in which the inherent mobility of human-transported robotics situate – and improve – multiple situational awareness. A plurality of computational resources, multiple sensory input/output devices and telecommunication modes, and programming languages enable rapidly developing and distributing software applications and physical hardware. Cyber-physical systems make it possible to monitor and collect data from physical bodily and environmental processes. Control systems make the data about physical systems available for software applications to track, directly measure, and react to changes within bodily and environmental processes of the physical world.

The question of how to design this “object” as an actor safeguarding paramedic safety, autonomy, and performance is answered by designating human-mediated teleparamedicine as an instance of human-based computation. The contemporary technologies from which WEHST is assembled are too immature and expensive to adapt to the dynamics of the real-world. However, human-based computation distributes the respective abilities and costs of humans and computer agents to achieve symbiotic human-computer interaction and thereby sufficiently adapt and subsequently evolve. The ubiquity of wearable human-based computation allows human and computer to continuously exchange roles of giving formalized problem descriptions and receiving solutions to interpret.[cxxxi]

Human-based computation may also reduce inherent stresses placed on human-mediators by dynamically adapting teleparamedicine organizational structures to human errors, creativity, and spontaneity. Furthermore, WEHST offers a discrete human-based computation platform with inbuilt and built-in autonomy and scalability allowing distribution of concurrent research and development efforts among dozens of disciplines and across thousands of participating organizations.

> We need repeatable methods. Due to the logistical complexity of human participation in human computation systems, we cannot simply employ extant software engineering methods to accomplish anything more than simple crowdsourcing. This is beginning to change, but in order to progress at a reasonable pace, putting more effort into Human Computation research and less into Human Computation engineering, we need a basic technical maturity. As it is, each novel manifestation of human computation requires a ground-up development effort. Thus, we will need the Human Computation equivalent of a printing press in order for research to move beyond a geologic rate.[158]

The question of how WEHST collects and conveys multimedia medical records of *and* for patients and paramedics in the field during remote telehealth supervision by specialists is answered by WEHST's subsumption architecture. Human-mediated telepresence generally, and specifically WEHST, decompose the complete behavior of telepresence media production into sub-behaviors organized into a gradient of layers working in parallel to generate outputs triggering or inhibiting other layers.

Within subsumption architecture's bottom-up control style the behavioral competence of each layer of hierarchy arises through selecting actions in reaction to sensory information. For example, a WEHST robot's lowest layer could be "self-awareness" pertinently updated on the fly regarding the current configuration of its body.

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[158] Michelucci, Pietro. Human Computation: A Manifesto. pp1021-1039. Handbook of Human Computation. Pietro Michelucci Editor. Springer Science+Business Media New York 2013. 1039 pages. P1028

The second layer would be "record media", which runs beneath the third layer "allocate control". Because WEHST must have "self-awareness" of its dynamic morphology in order to "record media" effectively, subsumption architecture produces a system of higher layers utilizing lower-level competencies. WEHST’s real-time situatedness, embodiment, intelligence, and emergence make it responsive to dynamic environments, capable of sensing and recovering from damage, prepared to coordinate control among distributed and competing loci, and wearable on and among moving bodies.

WEHST wearability overcomes many inherent weaknesses of subsumption architecture via the parallel control layers of human-based computation which offers episodic central control (without top-down architecture latency, instability, bulk, or cost). Interleaving human perception, control, and action layers into WEHST’s subsumption architecture enables adaptable action selection in real-time while maintaining a widely distributed system of activation and suppression. Human memory and understanding of language also permit adequate symbolic representation to learn complex actions and do in-depth mapping without compromising WEHST’s real-time interactions with dynamic environments.

Secondary questions regarding ANT contributions to design processes and products are answered by taking as a point of departure my own design work. Applying principles of agnosticism, symmetry, and free association in assembling an actor network inclusive of human-mediated teleparamedicine experiences, WEHST systems, and COMmand products only discover teleparamedicine actors describable as non-unitary and non-local. Thus, human and wearable robot relationships are neither human-centered nor computer-centered. However, translating my discoveries into design of a wearable engine for human-situated telepresence (WEHST) finds rigorous industrial design as ecologically-situated processes of simultaneous practice, pedagogy, and research. WEHST-grounded design research capabilities premise concurrency of research about, through, and for industrial design, and its parallels in basic, applied, and clinical research. [159] This uncertainty of purpose is contemporaneous with the purposeful indeterminacy of WEHST's concrete instantiation.

> The adaptability of clinical diagnostic methods suggests that they hold together as a fluid, rather than as a network. Something similar might be true for other technologies that transport well. Therefore we mobilize the metaphor of the fluid here to talk of the Bush Pump. In doing so we hope to contribute to an understanding of technology that may be of help in other contexts where artefacts and procedures are being developed for intractable settings which urgently need working tools. Because in travelling to 'unpredictable' places, an object that isn't too rigorously bounded, that doesn't impose itself but tries to serve, that is adaptable, flexible and responsive - in short, a fluid object - may well prove to be stronger than one which is firm.[160]

Describing the contribution of ANT to the design process is a wicked problem, as each conveyance deepens and diversifies the actor-networks concerned. ANT – as a negative argument – does not offer design solutions inasmuch as ANT embroils the designer in the actor networks which are described. Furthermore, the non-unitary subjectivity of the designer amplifies the disparity of stakeholder worldviews which again, emphasizes recursive problematization rather than establishing solutions. The constraints presented by resultant actor-networks change over time and are heterogeneous across the designers' subjectivities. The problem of the designer is never described by a definitive actor network.

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[159] Estrada and Lawhead. Gaming the Attention Economy. Handbook of Human Computation. Pietro Michelucci (Editor). Springer Science+Business Media New York 2013. 1039 pages.

[160] de Laet, Marianne and Mol, Annemarie. The Zimbabwe Bush Pump: Mechanics of a Fluid Technology. Sage Publications, Ltd. Studies of Science, Vol. 30, No. 2, (Apr., 2000), pp. 225-263 (P226). http://www.jstor.org/stable/285835 Accessed: 29/07/2008 09:06.

The WEHST computational textile design outcome is not then a plan, pattern, or paradigm as much as it is a design heuristic for not reducing the complexity of a product-system. Operationalizing this design then is an embodied process of experiential, empirical, experimental, investigative, and exploratory association of not a designer having processes but designer *as* processes.

> Even if Latour's work shifts Pasteur out of the centre by pointing to the network he needs, it also suggests (or has been read as suggesting) that innovation, even if it turns out to be the work of a large army, does need a general in order to spread out. This Machiavellian reading of Latour says that technologies depend on a power-seeking strategist who, given a laboratory, plots to change the world. And this is where the Bush Pump and its designer come in. They allow us to frame a different vision. The success of a technology does not necessarily depend on an engineer who masters the situation and subtly subdues everyone and everything involved. A serviceable (or even submissive) inventor may help spread technologies just as well - or even better. Effective actors need not stand out as solid statues but may fluidly dissolve into whatever it is they help achieve. [161]

To design a "thing" as complicated as WEHST it is inadequate to take ANT as simply a lens with which to construct an individual worldview. Instead, approaching the wicked problem of human-mediated teleparamedicine requires embracing ANT as ontology whereby the designs and the designer arise as continuous interplay of non-local and non-unitary actors.

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[161] de Laet and Mol*, op. cit.* The Zimbabwe Bush Pump. 2000. P227

7.35 Epilogue

This design research has been guided by the premise that paradoxes are productive. Paradoxes were apparent at every academic, studio, field, and professional, literature, methodological, and theoretical level of the investigation. I define productive paradoxes as those creating new knowledge.

The academic levels primary paradox is that while contentions perennially arise that it is impossible to do a practice-based Ph.D. – it is possible to create new knowledge through industrial design research. I build upon this paradox by designing a product with explicit parallel, research (for, through, and into design), pedagogical, and professional practice capabilities. This approach is also appropriate to advancing research in the field of design – and more widely into research design across all domains of research. I accomplish this through narrowly teleparamedicine-specific system-level architecture of WEHST which – while focusing on the acute embodiment and severe situatedness of individual paramedics operating helicopter external transport systems in extremely hazardous environments – is generalizable to wider research programs involving human bodies.

At levels of studio-based industrial design research practice I employed the principle of productive paradox to design an assemblage of eight interoperable suites of modules reconfigurable in real-time into multiple possible wearable system montages which change paramedic and WEHST shape, or morphology, as part of human-based – and situated – computing. Combined paramedic and WEHST morphologies are designed to adapt optimally to numerous external demands. Paramedic and WEHST embodiment can be mutually and autonomously re-shaped in response to external demands which change the morphology. This design applies human-in-the-loop personalization which allows off-the-shelf manufacturing and material technologies to produce a wearable and distributed morphological computing system. WEHST is an industrial design; and thus, while the object/assemblage plus programming/language does not as yet *entirely* exist – WEHST can be built using contemporary technologies.

A further studio-based paradox is that seemingly unitary and local designed objects may be anything but. For example, my initial overarching designs were of monolithic, complicated, fully integrated teleparamedicine garments that addressed a multitude of constraints. These began as complex integrated designs with little modularity, scalability and adaptivity. This stage focused on the environment designed the device from the outside-in. Over time these were decomposed and designed into the fabric of teleparamedicine and WEHST. WEHST design commenced with an extensive, cluttered, awkward, and restrictive garment and arrived at a material substrate for a platform composing a fabric allocating and partitioning human-mediated teleparamedicine actors into a textile of computation. Through continuous modeling processes, WEHST's system-level architecture of procedures and specifications emerged. Iteratively developing these models removed features until solely actor networks (ANT's) and constellations of physical black boxes and layers of fabric remained. This computational fabric, comprising eight interleaved families of wearable computing devices, emerges across multiple scales of: electro-mechanical elements; robust yet pliable components; highly specialized yet interoperable products; a generalizable yet bespoke system; personalized yet shared experiences; and enduring processes of transformation. The computational textile of COMmand, WEHST, and teleparamedicine constitute human, biological, analog, and digital hybrid computing deployable writ small and writ large.

At the level of my field-based industrial design research the productive paradox encompasses how the ethical concerns of conducting my field ethnography made a profound contribution towards shaping the practical design outcomes. The immediacy of these ethical concerns sensitized me to the many intimate interactions between designed hardware (and software) and fundamental medical ethical principles. For example, principles of “personal autonomy” and “informed consent” are applicable to decisions by both patients and paramedics. More so than their patients, various local and remote paramedicine tele-mediators, and teleparamedics themselves are both surveilled (by instruments and supervisors) and are surveillance instruments that must continuously request, re- request, and requisition individual and shared informed consent when making certain decisions. The paradoxical interplay of respect for personal autonomy of both patients and paramedics includes “supported autonomy” with teleparamedicine remote supervisors and wearable devices making temporary compromises to paramedic and patient personal autonomy in order to preserve their long-term autonomy. No existing technologies for teleparamedics working in the field adequately combine and configure hardware, software, middleware, and wetware to meet real-time ethical adaptation and evolutionary requirements.

At the level of my professional practice-based industrial design research, the fruitful paradox is that while I have spent seven years continuously seeking and evaluating the market and technical viability of commercial research instrumentation – and extensively cataloging the needs of basic, applied, and clinical researchers, research participants, and patients – I cannot disclose this in more than the most tangential detail. While the dissertation does not detail this extensive professional research practice because of my obligations of: maintaining confidentiality vis-à-vis relationships with and among employers, colleagues, and clients; non-disclosure of sensitive intellectual property and trade secrets. However, I can divulge that my research into wearable psychophysiological monitoring technologies – such as those intrinsic to ethical conduct of naturalistic research – explicitly confirmed that there are no existing technologies which meet the criteria of not only paramedics but also of independent *or* institutionally entangled professional researchers.

At the level of the literature the generative paradox is that while a particular author – Lynn Margulis – has been the clearest guiding voice throughout both the practical and theoretical aspects of my research, her central premise that the concept of individuality (and I would argue by extension the concept of centrality) is not supported by the evidence from cellular biology or ecology. Margulis balances the rigorous work of evaluating the minute details of evolutionary microbiology with some very 'big picture' implications arising from her research, which may be a natural consequence of research premised on radically alterior philosophical, and biologically concrete, compound perspectives.

> Former bacteria, as themselves or parts of larger cells, are still the most abundant forms of life on the planet. The strength of symbiosis as an evolutionary force undermines the prevalent notion of individuality as something fixed, something secure and sacred. A human being in particular is not single, but a composite. 'Our' bodies are actually joint property of the descendants of diverse ancestors. Individuality is not stuck at any one level, it that of our own species or pond water Amobea proteus. Most of our dry weight is bacteria, yet as citizens swarming in crowded streets and office buildings, viewing television, traveling in cars, and communicating by cellular and facsimile phone, humans disappear in a global swirl of activity, overwhelmed by emergent structures and abilities that could never be accomplished by individuals or even tribes of human predecessors. No single human can speak to another human, in real time, thousands of miles away.

> No single human can stand on the Moon. These are emergent abilities of superhumanity. Our global activities bring to mind the social insects, except that our 'hive' is nearly the entire biosphere.[162]

At the level of methodology the productive paradox is that by adhering to ANT principles of generalized symmetry – which reinforces my cooperative conception of the design discipline – designers are explicitly included among a wide swath of WEHST stakeholders. Industrial designers as stakeholders are especially distinct in my chosen instance of industrial design where specifically, the WEHST system (also a co-design participant) being designed to perform as a design research instrument and to shape research design. Furthermore, as an illustrative class of semi-autonomous designed objects WEHST is capable of performing limited self-study – in order to drive concurrent hardware and software adaptations and even limited evolutions – analogous to design. The methodological paradox presented by ANT symmetry is also instructive for approaching the extremes (from very small to very large) and multiplicities of scales of system-level specification as instances of industrial design.

Finally, at the level of theory the most productive paradox guiding my research is the phenomenon – articulated by Hans Moravec – underpinning the early successes of embodied and situated approaches to artificial intelligence and robotics: Moravec's paradox. Moravec worked in the 1980s in parallel to Rodney Brooks and Marvin Minsky to understand why, and answer how, in artificial intelligence research,

> The hard problems are easy and the easy problems are hard. The mental abilities of a four-year-old that we take for granted – recognizing a face, lifting a pencil, walking across a room, answering a question – in fact solve some of the hardest engineering problems ever conceived.[163]

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[162] Margulis, Lynn and Sagan, Dorion. What is life? Simon and Schuster. Toronto. 1995. P192
[163] Pinker, Steven. The Language Instinct: How The Mind Creates Language. Perennial Modern Classics, Harper, 1994

High-level reasoning requiring very limited computation resources – are in stark contrast with low-level sensorimotor skills demanding vast computational resources. Moravec explains how we underestimate the complexity of processes we perform easily, which have evolved through natural selection over billions of years, and of which we are mostly unconscious (In absence of a widely accepted definition of consciousness). Simultaneously, we are acutely aware of, and attribute great refinement to, recently acquired simple abilities such as abstract thought processes we perform poorly. This is a basis for designers seeking to model and reverse-engineer human or non-human biological phenomena. [164]

> Encoded in the large, highly evolved sensory and motor portions of the human brain is a billion years of experience about the nature of the world and how to survive in it. The deliberative process we call reasoning is, I believe, the thinnest veneer of human thought, effective only because it is supported by this much older and much more powerful, though usually unconscious, sensorimotor knowledge. We are all prodigious Olympians in perceptual and motor areas, so good that we make the difficult look easy. Abstract thought, though, is a new trick, perhaps less than 100 thousand years old. We have not yet mastered it. It is not all that intrinsically difficult; it just seems so when we do it.[165]

Moravec's paradox is thus a tool for inverting assumptions about intelligence, whereby refined and robust intelligence is embodied and embedded. While inversely, abstract intelligence is poorly refined, badly defined, only partly understood as correlated with embodiment, and rarely considered in an extended setting of being what "highly educated male scientists found challenging." Perhaps abstract intelligence is an epiphenomenon of cultural evolution.[166] The paradoxical contribution to highly particular

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[164] Moravec, Hans. Mind Children: The Future of Robot and Human Intelligence. Harvard University Press, 1988. P15-16, 214 pages
[165] *Ibid.*
[166] Brooks, Rodney A. Flesh and Machines: How Robots Will Change Us. Vintage Books, 2002. 260 pages. P36

design projects of understanding evolution and embodiment is by reciprocally applying computational design projects/products to real-world situated human embodiment – obliging consideration of human beings as a technology – *né* extended ecosystem – not to be underestimated as a resource.

Endnotes

[i] A wicked problem is a (partial, inconsistent, and dynamic) problem resistant to resolution because of complex interdependencies. "Wicked" is used here as a technical (rather than moral) term denoting resistance to being simplified to a “solution”.
[ii] A brief recap of Canada-research chair interviewees, with the goal of illustrating the research design orientation of my ethnographic observations, is as follows: Between 2007 and 2009 I interviewed this group of Canada Research Chair’s. All quotes in this section are from their respective CRC website biographies. Dr. Uri Shalev, Concordia University-based Canada Research Chair in the Neurobiology of Drug Abuse, uses “animal models of drug taking and mental illness to study interactions between underlying neural mechanisms and energy balance systems. The research may lead to a new approach to the treatment of drug addicts.” Dr. Steven High, Concordia University-based Canada Research Chair in Public History, uses “oral history to examine how people remember the past and how they use historical memory to make sense of their individual and collective realities when confronted by transformative change. The research enhances historical understanding of the social impact of transformative change and applies new digital technologies to the study of oral history.” Dr. Nigel Rapport, then Concordia University-based, Canada Research Chair in Globalization, Citizenship, and Social Justice, explores “the complexity of global social and cultural milieux, the cosmopolitan experience of the citizen, and the openness of a just society. The research will lead to an improved understanding of globalization, citizenship, and social justice.” Dr. Mark A. Ellenbogen, Concordia University-based Canada Research Chair in Developmental Psychopathology, executes “multidisciplinary longitudinal research that examines the developmental antecedents of maladjustment, including the role of stress, family functioning, hormonal changes, and cognitive factors. The research aims to lead to the development of effective prevention strategies for mental health problems, such as depression.” Dr. Jeffrey Mogil, McGill University-based Canada Research Chair in the Genetics of Pain, researches “genetics; individual sensitivities to pain; and drug therapies tailored to individual patients.” Dr. Cornelius Borck, McGill University-based Canada Research Chair in Philosophy and Language of Medicine, examines “the role of the life sciences in the cultural definition of the human. Research Relevance The research aims to provide a better understanding of the impact of clinical practices, diagnostic technologies, and research programs on the cultural constructs of body, mind, and self.” Dr. Mindy Levin, McGill University-based Canada Research Chair in Motor Recovery and Rehabilitation, conducted a program entitled: “Enhancing the power to heal: innovations in motor learning and rehabilitation after brain damage.” She researches “optimizing the recovery of arm and hand after a brain injury. The research is leading to the development of new diagnostic and therapeutic tools for children and adults with motor problems.” Dr. Yong Zeng, Concordia University-based Canada Research Chair in Design Science and head of the Concordia Institute for Information Systems Engineering. His research is towards “establishing a formal design science for understanding design activities and developing design tools. The research aims to develop computer-aided conceptual design tools for the design and manufacturing industry to enhance the industry’s competitiveness in the global market.” My measure of success for this ethnographic research was participation in challenging, productive, widely relevant dialogues with established researchers holding valuable perspectives on applying understanding of research to the challenges of rigorous and transferrable human-mediated teleparamedicine design.
[iii] In January of 2010, to reinforce the researcher-oriented component of my ethnographic research, I visited the Santa Fe Institute (SFI), in Santa Fe, New Mexico. I traveled to the Santa Fe Institute to conduct a series of recorded and non-recorded structured interviews on two topics: the evolution of technology and material culture; and, best practices of research into complex phenomena. These interviews are within the scope of investigation of this SPEC 834W course. At that time I interviewed researchers Chris Wood, Bela Nagy, Jennifer Dunne, Luis Bettencourt, and philosopher in residence Daniel Dennett. I also had the opportunity to meet, and conduct non-recorded interviews with, a number of other SFI researchers and staff. Many of the SFI researchers endorsed my research goals sand methods and validated my research focus. They strongly encouraged me to persevere in maintaining my interest in an area, which remains largely unfunded. My interviews informed my investigation of complex adaptive systems research best practices for industrial design, the roles of evolving complex phenomena within models of design sustainability, and permit my own professional research experiences and perspectives to contribute directly to the research goals of other researchers in areas of complex phenomenon.

[iv] Notable exceptions are the British Columbia ambulance service Infant Transport Team (BCAS ITT), whose scope of practice expressly bridges this shortfall.
[v] Computational textiles are relatively synonymous with smart fabrics, electronic textiles, or e-textiles. Computational textiles integrate computation with fabric in both wearable and non-worn applications related to the areas of fashion, sports, entertainment, medical, architecture, and electronic components or devices. The computing capabilities for textiles include many possible combinations of digital, electronic analog, analog, and human-based computation. Computational textiles are deeply relevant to the social transparency, individual comfort, economy, technical performance, and environmental versatility of telehealth systems. Fundamental industrial design challenges for computational textiles include manufacturability, durability, performance, serviceability, comfort, and personalization.
[vi] Sousveillance is the use of personal media technologies enabling participants to record individual or community-level activity. Sousveillance is particularly poignant as inverse-surveillance conducted with wider spheres of surveillance.
[vii] Equiveillance is a state of (or desire to achieve) both creating and having access to surveillance data. This equilibrium between surveillance and sousveillance permits individuals to gather evidence themselves *and* construct their own understandings of it.
[viii] This paramedic worn product system for medical telepresence allows the presence and practice of a skilled medical specialist (in situ) who is isolated from the patient to be mediated (in vivo) by a paramedic co-present with the patient, assisted by an online communication relay operator (ex situ) and semi-autonomous on-the-body artificial intelligence (in vitro).
[ix] My research draws from and aims to add to British Columbia's paramedicine community's telehealth expertise arising from vast transport distances. British Columbia's paramedics conduct high-risk SAR operations in air, forest, alpine, confined space, and high angle settings obliging further preparedness for chemical-biological-radiological-nuclear-explosive hazards. British Columbia's extreme geography, unevenly distributed population and infrastructure, high medical-care standards, and large call volume oblige British Columbia paramedics to be prepared to work with remote specialists via telehealth. Consequently, British Columbia Ambulance Service (BCAS) paramedics are members of, and employed by, an organization with over 100 years of history combining appropriate technologies and best practices towards early adoption of innovative telehealth. Secondary beneficiaries include regional, provincial, national, and international governments and NGO's responsible for SAR and CBRNe operations. Tertiary beneficiaries include taxpayers, medical insurance payees and providers, and researchers investigating public health, telehealth, epidemiology, public safety, occupational health & safety, telecommunication, telepresence, wearable computing, electronic textiles, and media-arts.
[x] Jonas posits that research *through* design is the only authentic research paradigm. This is because research through design is grounded in projects. Research through design creates new knowledge through an action-reflection approach - which emphasizes the research objective is new knowledge creation *of* design. Jonas, Wolfgang. Design Research and its Meaning to the Methodological Development of the Discipline. In R. Michel (Ed.), *Design Research Now*. Basel: Birkhäuser.
[xi] Such human-*based* design gives human-mediated teleparamedicine and WEHST as instances of human-based computation subverting individualistic or anthropocentric perspectives.
xii The paradigm of situated computation extends cognitive science concepts of situated cognition to computation. Situated computation reconceptualises computation as first-person knowledge created by operating the programs. This is contrary to computation conceived as fixed and objective programming of knowledge into the computing system in-advance of operating the programs. This first-person knowledge is available throughout operation of the system, and enables the system's to develop varying degrees of aptitude – or at least familiarity – with particular situations.

[xiv] Exploratory research is through my parallel processes of field ethnography and is as an ongoing formal and informal participatory design process with teleparamedicine and WEHST stakeholders. These participants range from medical professionals to electronic component suppliers and manufacturers, all of whom are attuned to the specific risks of reductive application of scientific methods precluding insight or innovation. The speculative research purposes the ambitious scale of my project and reflects the recursivity and processuality explicit in the human-mediated teleparamedicine and WEHST design. Such

purposeful indeterminacy welcome controversies as essential for ANT-led participatory design processes. My professional practice in medical research instrument research and development and manufacturing is also translational research from multiple directions. Translation of basic science findings to practical research instrumentation development applications is recursive – as research instrument research design first draws from scientific literature, to then be used in basic, applied, and clinical research. Then it engages scientific communities at the level of research design requirements going beyond applying scientific literature. Daily transactions among basic researchers, their employers and employees, professional and regulatory bodies, and industrial suppliers make their research design concurrent with instrument development. translating basic science to application development in-house is within the research and development lab and team, is among teams and individuals including marketing, sales, support, quality assurance, shipping, accounting; production especially apply basic science in tandem with research and development teams. Commercial in-house research and development is mutually entrained among basic, applied, and clinical researchers. This acquaints me with an array of research designs and regulatory and business models suiting complex products and discerning clientele. Aligning multiple research perspectives by means of parallel exploratory, speculative, and translational research purposes enhances design process rigor. Beginning with exploration of the boundaries of the basic principles, then speculating upon applying those discoveries, and finally translating findings into research designs' clinical equipoise in recursive research practices.

[xv] Donna Haraway coined, in service of science and technology studies, the term "material-semiotic". (Suchman 2007, P261) She hatched the cyborg "politically generative trope" (Law 2004, P158) which best fits my own design specialization. Cyborgs set plates for companion species at the table. (Her cyborg's partial connections among differentiated parts yet related which cannot be conflated.) Attuned to the science wars' gestalt, Haraway does, in Latour's words, "direct our attention simultaneously to the work of purification and the work of hybridization." (Suchman 2007, P11) Haraway's cyborg choreographies of Latour's "things" are the liveliest models for the wearable telepresence systems I propose for coordinating superpositioning embodiments. (Haraway 2008, P250-251) Her studies of primatologists and laboratory animals give concrete cases where my designs fit the interstices of compound (Haraway 2008, P251) bodies and technologies in perpetual translation. Lucy Suchman's writing on human-machine boundaries is also informed by Latour's contribution to her non-reductive understanding of why and how to, in Lucy Suchman's words: "Develop a discourse that recognizes the deep mutual constitution of humans, and artifacts without losing their particularities. Recognizing the interrelations of humans and machines, in other words, does not mean that there are no differences. The problem rather is how to understand our differences differently." (Suchman 2007, P260)

[xvi] Michel Callon also shapes Suchman's take on ANT's networked actants *becoming* in dynamic morphological relation. She considers agency an outcome of symmetrical, heterogeneous entities emergence through participation in various networks of relations. (Suchman 2007, P261) She articulates social material agency as "an effect of practices that are multiply distributed and contingently enacted." (Suchman 2007, P267) While Suchman does not wholly embrace ANT's generalized symmetry. She acknowledges the scope and value of "intervention into sociological preoccupations with human agency." (Suchman 2007, P269-70)

[xvii] Arthur Tatnall, editor of the *International Journal of Actor-network Theory and Technological Innovation* (IJANTTI), assembles a host of appropriately practical texts with specific empirical processes of ANT "[…] as a means of understanding various socio-technical phenomena and providing examples and case studies of technological innovation." (Tatnall, IJANTTI, 2009, 1116) IJANTTI's authors apply ANT across general theoretical and specific empirical levels adhering to the spirit of ANT with varying rigor, as some flirt with ANT as an explanatory framework. However, ANT's strengths include its permissiveness to build upon and hold multiple viewpoints in service of successful practices. IJANTTI texts include many case studies applying ANT concepts such as translation and black-boxing as analytical tools advancing innovation in information and communications technologies (ICT). To this end, ANT is often compared and contrasted to a range of historical, contemporary and speculative theoretical frameworks, such as innovation diffusion or ecological models. ANT's accommodating multiple perspectives and application methods in case studies are useful for writing up research comparing parallel literatures with ANT. ANT establishes and maintains researchers' ethos by stipulating the multiplicity of actors conveyed, readership engaged, and researcher non-unitary subjectivity. IJANTTI discusses particular information and

communications technologies enterprises and initiatives by academic, industry, government, and non-governmental organizations in regional, national, multinational, or transnational settings. These authors are concerned with who the actors are, how they relate to one another, and how they relate to explicit ANT roles. ANT processes and mixed methods employed by IJANTTI authors practically apply constructivist approaches to philosophy of science and technology. Develop a discourse that recognizes the deep mutual constitution of humans, and artifacts without losing their particularities. Recognizing the interrelations of humans and machines, in other words, does not mean that there are no differences. The problem rather is how to understand our differences differently.

[xviii] Even a dead, actorless text, tracing no network, is a successful experiment. A writer clutching at a particular actor network never entirely fails to translate. A texts provenance of trees, sweat, steel, mud, blood, and oil spell an enchantment which may or may not overlap with the readers blind spot.

[xix] Considering ANT black boxing as analogous to “black box testing” concepts from software and hardware development exemplifies the practical value of ANT thinking. For example, instances of operator black-box testing occur in hands-voice-free radio operation situations where medical and rescue matériel are carried reliably and stably by the operator. This matériel is black-boxed within the network of allies. However stable over time, teleparamedicine settings periodically perturb translation processes within the paramedic-as-actant black box. These disruptions mandate actively checking paramedic actants’ performance by inputting valid signals to be checked against correct outputs from the black boxed paramedic plus radio plus teleparamedicine materiel. Specification and requirement-based testing does not oblige comprehensive or specific knowledge of paramedics’ internal structure. Even paramedic situatedness in sensory or mobility challenging rescue environments is secondary for black box testing. The inverse of a black box are systems where the internal components are accessible for inspection. Black box opacity or coherence juxtaposes with COMmand’s periodic “white-box” or “glass-box” levels of disclosure during training, proctorship, system-level configuration and participatory design.

[xx] When radio microphones fail to detect operators voice, or are swamped by loud or continuous ambient sound; when operators similarly does not sense/detect their own radio; when radio speech activation is over/under responsive; when speech recognition accuracy is low; when manual control of radio push-to-talk buttons is on reachable; and when manual or voice-control of radio settings required time-consuming, error-prone navigation menu sequences.

[xxi] However, COMmand could be black-boxed as a technology package consisting of a small electronic circuit board populated with standard electrical components and connectors integrated inside radios of licensed vendors. The seeming ease of this approach is deceptive. The advantage of a discrete COMmand module over a sub-assembly hidden inside an otherwise generic-looking radio is the ease of reconfiguring a small group of discrete peripherals. Tethering a peripheral to the radio does not excessively disrupt the workings of the tightly sealed network of radio subsystems and existing human-to-radio assemblages.

[xxii] On-the-fly sensor/emitter configuration has intermittent formative stages of contestation of various competing hybrid subsystems versus mono-modal configurations.

[xxiii] Exaptation is a co-option process throughout adaptations in the purpose of a trait during evolution. Through processes of exaptation, traits serving one particular function evolve to subsequently serve another purpose.

[xxiv] Teleonomy is the seeming purposefulness and directedness of those living or computational processes that constitute the adaptive and reproducing organisms’ evolution.

[xxv] Data collection was as industrial design literature review conducted as seeking prototypical relationships within the material to inform the constraints and constituents of the germinal design work. Data analysis was constituted as processes of conceptual design seeking to insinuate the constraints and structures developing within the literature review, as bases for intermediate design iterations of teleparamedical and ethological tools at, or from, multiple sites, scale, perspectives, and conceptual grounds. Data synthesis was through research and development of iterations of the creative triptych of black boxes of human-mediated teleparamedicine, WEHST, and COMmand.

[xxvi] Data evaluation was shaped greatly by the wide availability of electronic or photocopied versions of the materials used. I sought to read most writing by Haraway and most writing by Margulis (and Sagan) on the topic of symbiogenesis. The two authors are sampled along a longer timeline, and at a greater depth, than if I was just touching what I was initially directed to by other authors, and by my own initial

assessments of their oeuvres. This also presents the authors and their works at many different points of development and focus. Their bodies of work are a series of traces of their personal practices and professional communities, and show many communities of peers, and many aspects of non-unitary authorial subjects.

[xxvii] Accounting for the decentralized agency of human-based computation may embrace interpreting possible revelations of paramedics' possible non-unitary telos as models for the distributed technological agency of their tools, and possible consideration of agency at levels of telemedical ecosystems.

[xxviii] Haraway's post-structuralism and cyborg feminism led her to Margulis' symbiogenesis which underwrites her work on companion species. Margulis' endosymbiosis theories led her to Gaia theory.

[xxix] The background to this extended reading of Donna Haraway and Lynn Margulis is a broader investigation of how and why interdisciplinary research and scholarship, specifically in the areas of evolution and material culture, accords new bases for practices and theories of ecological subjectivity as a partial basis of HBC industrial design.

[xxx] While much of this review considers what the authors say individually, it is important to note that both authors are preoccupied with some converging points. Some of this overlap has very effectively guided me towards the discovery of process philosophy and process theory, as established, yet understated philosophical and theoretical presences which provide specific injunctions for, explicating, if not occasionally resolving, several big questions Haraway and Margulis hold in common. Their overlapping concerns include: the source of Darwin's missing variation; the complexity and emergence of boundary formations; the phenomenon of complex entanglement; the biological basis of cultural emergence; the value of understanding symbiogenesis as a phenomenon with wide implications for science, philosophy of science, psychology, sociology and philosophy; the role of autopoiesis in debates about teleology in biology; and Alfred North Whitehead's "fallacy of misplaced concreteness." Fortuitously for my research, Haraway and Margulis both explicitly refer to Alfred North Whitehead's "fallacy of misplaced concreteness" as a counter to their personal critics' arguments, and as a basis for formulating research prescriptions for resolving intractable dilemmas associated with investigating the emergent properties of a system of systems (second-order cybernetic systems).

[xxxi] Scenarios, as much as, and perhaps more overtly than the discrete product they indirectly encode, continuously adapted my interview (objectives and goals) process (in terms of who, what, when, where, why, and how) by identifying and resolving problems within the purview of particular participants. Scenarios emerge by observations and through interviews designs emerge as scenarios situating a participatory and collaborative practice of bottom-up WEHST and top-down human-mediated teleparamedicine design distributed among designers, clients, and users; and supporting consideration of abandoning the concept of the individual as centre. Observations are of the operating environment in the tele-medical ecological ground that teleparamedicine figures emerge from.

[xxxii] While on-site at the *Joint Rescue Coordination Centre*, I was regaled with tales of two air crashes in the previous two weeks. I was assured the probability of anything requiring the dispatch of search and rescue technicians was low. The already rapid daily tempo of *Joint Rescue Coordination Centre* coordination of federal, provincial and volunteer resources was interrupted several hours later. A mining exploration helicopter crashed into the side of a remote northern British Columbia valley. Search and rescue technicians were deployed to rescue the helicopter crew, supported by many other participants from across western Canada. Several years prior, while in silviculture I had worked in the shadows of this same valley's steep cliffs, from which a helicopter and crew were now suspended by a snagged long-line and cargo net. This made the rescue particularly poignant for me. The serendipity of my particular boots-on-the-ground experience at this crash site made this *Joint Rescue Coordination Centre* experience more than passive observation. My embodied understanding of the particularly extreme topography, geography, weather, and ecology of this site shaped my conceptions in real-time of hypothetical teleparamedicine toolset requirements.

[xxxiii] The value of teleparamedicine for search and rescue technicians helicopter external transport systems and chemical-biological-radiological-nuclear-explosive response was described in three separate experiences of my preeminent search and rescue technician participant, Sergeant Ron Condly. His (yes, they are all men to date) first mission was rescuing the crew of a burning barge in the Strait of Georgia. The search and rescue technicians were working in explicitly hazmat conditions as the barge was laden with propane, diesel, gasoline, and explosives. Another example was a train crash near Kamloops, British

Columbia, in which a train carrying toxic cargo derailed and caught fire in steep, rocky terrain and search and rescue technicians faced peril to rescue the crew. A final example was a body recovery of an F-18 pilot killed in a crash in the Rocky Mountains, where highly toxic materials in the airframe were possibly combusting in an impact fire.

[xxxiv] The resultant train crash scenario was developed years in advance of the Lac-Mégantic disaster, and was vetted as a plausible and fitting case to drive teleparamedicine and WEHST design.

[xxxv] This scenario is based on observations of the infant transport team trade being significantly more a community than other British Columbia Ambulance Service paramedic trades I encountered. This was verified by comparison with other trades included basic life support (BLS), primary care paramedic (PCP), advanced life support (ALS), and critical care transport (CCT). The deeply nuanced relationships within the infant transport team with pediatricians and with patients, and the great degree of mutual respect demonstrated among infant transport team members was self-reported. The profound professionalism exhibited by the infant transport team was reiterated by all other British Columbia Ambulance Service trades, Justice Institute faculty and staff, and physicians across British Columbia.

[xxxvi] There are perhaps degrees of topical relevance between research topics to consider when qualifying this observation. Despite this caveat, it became clear to me in industry how creating new knowledge does not require a mandate, budget, or acclaim. New thinking required a diverse and multidisciplinary community.

[xxxvii] My early training as an industrial designer acquainted me with laboratories. When I returned to college in 1998, I already planned to design wearable computing-based telepresence systems. I enrolled in a human biology stream, which was congruent with the processuality of my ecology-oriented worldview fostered living and working in rural British Columbia and the Yukon Territories. First studying, then tutoring, then assistant-teaching in human anatomy and physiology, cell biology, and exercise physiology courses was in tandem with rigorous laboratory components. My colleagues were nursing, pre-medicine, kinesiology and pharmacy-stream students. We all submitted to the culture of trials and experimentation inculcated by shared experiences in labs. Later, in 2003 to 2004, I interned in Vancouver's *GF Strong Rehab hospital* [spinal cord injury] assistive device clinic and at the *Neil Squire Brain-Computer Interface Research Lab* located in the same hospital. Clinical and laboratory Internships positioned me to see basic research conducted and applied in clinical settings. The *Neil Squire* team was led by quadriplegia researchers of whom some were quadriplegics who could directly benefit from its results, rigor, and contribution to the wider brain-computer interface research data sets and communities. (recirculated perspectives on embodiment) Arriving in Montréal in August 2004, to pursue a *Digital Design Art Graduate* Diploma focussed on wearable computing and electronic textiles I gravitated to the Hexagram research labs. In 2003 I had independently arranged visits with, and interviews of, several professors at the MIT's Media Lab the year before. The Media Lab had made me immediately distrustful of their combination of overt military funding and ambiguous research goals. The particular MIT labs I was interested in studying in seemingly offered very narrow degrees of freedom to challenge the dominant ethos of military-oriented research. Conversely, Hexagram's research-creation model offered labs where the aesthetic and ethical aspects met with practical and political outcomes in areas of electronic textiles. The ethos of researchers associated with these labs acknowledged and embraced fibres-grounded technologies' artistic and cultural provenance. Cognizance of fibres practices as cultural, embodied, and not neatly reducible, includes recognition of swaths of textiles' repertoire of techniques and materials are not entirely transmissible as industry-wide applications or procedures. The convergence of a community of textile artists and artisans, a R&D and lab driven textile industry, a research-creation community with overlapping interests in electronic textiles prompted me to seek to remain in Montréal.

[xxxviii] In 2005 to 2008 I entered employment as a laboratory research assistant in earnest. Commencing in Hexagram's *Université de Montréal Formlab*, I immediately discovered answers to my questions about the role of theory and practice in industrial design research. The *Formlab* research team was conducting *Le projet Méta-Morphose* to plumb automated manufacturing and prototyping technologies for physical modeling in the design process. Investigating new models of intervention made possible by these techniques gave me insight into how ecological sustainability is in large part established and maintained through distributed processes including distributed manufacturing, whole-lifecycle analysis, and mass-personalization. Further work as an industrial design research assistant in Hexagram research labs followed, with the *Mobile Media Lab* bringing me into a multi-disciplinary team supporting a mobile

electronic research platform. These innovative research-creation (R&C) and R&D processes, delivered technologies by distributing creative efforts widely enough among all participants to give rise to years-ahead-of-the-curve artifacts. The *Institute of Everyday Life* (IEL) with Ingrid Bachmann investigated the design, production, and performance of animatronic electronic textiles. The *Interactive Multimedia Playroom* with Dr. Rosemary Mountain investigated cross-modality sensory coding and categorization while accounting for the interplay of specific sensory modalities with the ergonomics of full-body spatial interfaces. *d_verse* was PK Langshaw's Hexagram Black Box-based transdisciplinary performative environments blending electronic textiles and dance performance in immersive interactive multimedia environments. The *Wearable Absence* project at *Studio subTela* created exhibition and performance pieces blending electronic textiles, physiological sensing, interactive garments, and mobile telepresence though coupling advanced engineering and computer science with fundamentally artisanal textile construction processes.

[xxxix] Biases in and among academic and industry research programs are ameliorated somewhat by ANT-influenced recognition of habitual disregard for, and systematic suppression of, non-human actants and furthermore, reduce humans to unitary subjects. Fortunately, the Science Wars had cooled enough for my research design to align with ANT and research-creation modalities. However, the resources these constructivist approaches could garner within academic settings did not grant adequate access to the research matériel or technology-as-practice multidisciplinary communities required to apply my specific industrial design skill set to studies acting directly on and through economic and industrial infrastructure constraining and shaping wider research paradigms.

[xl] The 2008 global economic crisis occurred while I was working in intelligent textile R&D in the *Centre-de Transfert de Technologie/ Fashion Technology Transfer Centre* (CTTM) laboratories. This academic-industry technology transfer lab connected in real-time to thousands of small, medium, and large businesses to demonstrate how the research and development driven aspects garment and textile industry were somewhat buffered from many of the repercussions of the economic melt-down. These experiences established for me how, from the lab-centred perspective, economic players were not passive. Actors' fates were much more in their own hands. Within Quebec's (largely unique outside of pockets in Germany, France, the USA, and Japan) research and development driven business responded to perturbations differently than commonly expected or experienced more widely in sectors not driven by innovation. These research and development laboratory contingent actors tracked different trajectories than the rest of their sectors or of the wider global economy. They shifted, faltered, but by and large did not fail, and their horizontal associations and quality and innovation-oriented business programs buffered them at least for a time from the worst of the turmoil. These first commercial research and development laboratory experiences, at *Centre-de Transfert de Technologie* and particularly its *Techno-Espace: Laboratoire Technologique du Vêtement*, taught me the ropes as an electronic-textiles and intelligent-garment researcher.

[xli] The *Janro* team was led by the father-son pair of polymaths, Roman Kroitor and his son Paul, who had years before developed the IMAX cinema system. Familiar with the travails of application-driven research and development, Roman and Paul helmed a balanced team of programmers, machine-vision computer scientists, physicists, animators, ethnographers, visual artists and administrators. Their team navigated the *Stereoscopic ANimation Drawing DEvice (SANDDE)*, a monolithic piece of software and hardware, into position in the animation market. We vigorously pursued parallel hardware technical leads – most of them anticipated to partly fail usability testing.– Planned hardware failures lived up to their promise to smooth the transition from multiple working prototypes to marketable product.

[xlii] Government funding bodies rapidly expedited funding for student researchers, and evidently placed a premium on students gaining real-world research experience. Government funding was more agnostic in terms of the value of academic-to-industry transfer of skills or intellectual property, so when actual contributions to researcher were based on particular academic skillsets such as ethnographic research methods, it was duly acknowledged.

[xliii] Considerable studio time was spent inventing and evaluating tools for reducing problem complexity via templates, vocabularies, and taxonomies. These aided selection of technical and conceptual approaches to specific sub-problems. Decreasing the complexity also strengthened my attention to the most relevant designers, environments, clients, and user collaborations. This guided my selection and application of processuality congruent approaches to textiles as a complex only partly apprehensible as a paradigm.

[xliv] Similarly, movement in studios cultivated heightened awareness of, and progressively voluntary relation with, my own psychophysiological states. Meditation studios were punctuated by breath, and in my case an audibly ringing titanium heart valve offered feedback amplifying voluntary control of physiology – much as the COMmand, WEHST, and teleparamedicine propose.
[xlv] My drawings are more figurative than most traditional industrial design drawing practices. These drawings are divested of particularity emphasize generic user silhouettes *sans* explicitly interior or exterior worlds. Drawing objects in context and in relation, rather than as subassemblies or assemblies of components standing isolated, showed the motion and emotion of use. Narratives dressed my human-in-environment figurations differently than would a traditional computer assisted drawing. Narratives applied patterns from interior physiological and external ecological worlds to an increasingly complex and inclusive model of teleparamedicine-situated human-based computation processes.
[xlvi] Prototyping included testing of designs, design processes, design pedagogy, designed objects, research design, process design, design environments, and design collaborations.
[xlvii] This monitoring extends the fundamental medical ethical principle of patient "personal autonomy" and "informed consent" to decisions by both patients and paramedics. As teleparamedicine mediators, paramedics are both surveilled and are surveillance instruments that must request and establish individual and shared informed consent when making certain decisions. The interplay of respect for personal autonomy of both patients and paramedics includes "supported autonomy" with teleparamedicine remote supervisors and wearable devices making temporary compromises to paramedic and patient personal autonomy in order to preserve their long-term autonomy.
[xlviii] Occurring in real-time and asynchronously, control with local and remote participation is continuously reassembled toward mutual responsivity between contextually focal and peripheral control. As an instance of subsidiary control processes, control devolves control to the least-centralized actors able to address specific sub-problems of system-level improvement goals of multilateral control of telepresence and care-delivery. (Brooks, Rodney. Intelligence without Representation. Artificial Intelligence, Volume 47. 1991. P139-159) Wearable technologies' embedded communication modalities offer intelligent control through feedforward networks continuously creating new techniques of system control and identification using mixed computing approaches that distribute control of radios across body sites and among local and remote sensed phenomena. Mixed problem-solving arrangements of neural networks, fuzzy logic or check algorithms first continuously map input states and, second, navigate a dynamic system toward preferred outcomes.
[xlix] The mechanical and electronic robustness of wearable systems includes balancing granularity (in terms of size, shape, and density) with partial redundancy when physically scaling the system. This trade-off engenders adaptive wearable modules with some self-healing capabilities during "normal failures" in typically dynamic or extreme environments. Decentralized wearable telepresence architectures provides for intermittent remote involvement which supports failure detection and recovery via networked capabilities for managing software applications and multimedia. Decentralization offers some means to reduce the operational cost of COMmand and WEHST being on the body in terms of power, processing, weight, size and shape, and in terms of cognitive and other bodily resources of the wearer.
[l] Paramedics' ecological embodied, embedded, and extended perspectives (Robbins, 2009. P1-9) are continuously *becoming* wearable through capacities for local and remote sensing and acting with and without cooperation of paramedics' bodies. Device sensor inputs from environments and effector outputs include paramedic sensorimotor modalities as a basis for device internally coding any specific representations (Robbins, 2009. P4). Paramedics constitute the foundation of interdependent assembly processes of wearing devices. Existing technologies embedded on paramedics cooperate with, co-opt, and mimic WEHST capabilities for "off-loading cognitive work on to the environment, a useful way to boost efficiency and extend one's epistemic reach."(Robbins, 2009. P6)
[li] Wearer and worns' extended conception of wearable *becoming* outside the envelope of discrete operators and devices is extensible to ecological perspectives. Wearability *becomes* through ecological situatedness of paramedic bodily reflexivity. This is similar to approaches to Nouvelle AI. I evaluate existing technologies against a definition of wearability cognizant of field operator physical and cognitive loads, and technical and ecological situatedness.
[lii] Customization is when something different from the standard offering is requested. Customization is letting the actor control their experience. Personalization is when an interactive "conversation" with

another actor occurs. In personalization the content adapts itself based on the actors profile, and guides the actors experience to provide something different (possibly even novel) than expected. The customization and personalization of real-world ready wearable systems needs to be evidence-based in order to be embedded in extended telehealth applications. Customization and personalization of wearable systems also serves wearers, designers, organizations, employers, policymakers, regulators, and human factors researchers.

[liii] Contemporary wearable technologies are also considered in terms of personalization of wearable technologies to suit particular individuals with specific scopes of practice. Personalization is increasingly feasible as individual electronic components become small, flexible, and granular enough to be worn in thousands of combinations and configurations on, or as, garments.

[liv] Teleparamedicine wearability evaluation proceeds as instances of socially distributed cognition as telepresence is considered as information transduced across embodied, embedded and extended modalities, and as a consequence of specific processes of joint attention distributed across sites.

[lv] Wearable telepresence constitutes human-based computation conducted in extended settings combining transport systems (HETS); protective suits, harnesses, and breathing-apparatus; operating medical instruments or rescue equipment; and combinations of physical, sensory, and cognitive overload or failure. Combined efforts of paramedics, plus design and research stakeholders, are linked by wearable technology into a functional unit of actors. Such team embodiments transform information generated by wearables into various representational states of maps, coordinates, protocols, care plans, electrical records, and policies. Practice-relevant study processes are often computationally intensive, in real-time, and preclude cloud-based computation as it frequently breaks down in first-response telecommunication environments. Therefore, deploying adequate computational resources requires direct contact with, or near proximity to, paramedics' bodies.

[lvi] Humanoid robots include the *Atlas* robot from Boston Dynamics (http://www.bostondynamics.com/) and the *HRP-2* robot of Japan's SCHAFT Inc. (http://schaft-inc.jp/). These robots are aimed directly at search-and-rescue and chemical-biological-radiological-nuclear-explosive environments too dangerous for human paramedics. Robots may be remotely operated to give limited telemedical care to patients. The WEHST toolset I propose is also wearable by humanoid robots, and could add considerable value to existing and emerging telerobotics platforms.

Figure 8.1: *Atlas* from *Boston Dynamics; HRP-2 from SCHAFT Inc.*

[lvii] Giving human embodiment as the basis of human-in-the-loop control makes human operators integral to processes of teleparamedicine becoming embodied, embedded and extended within loosely coupled technologies and sites. Sufficiently flexible parasitic humanoid-to-human coupling preserves *and* requires appropriate degrees of decentralization and autonomy. An instance of human-based computation, the parasitic humanoid prescriptively delimits ergonomic challenges of individualized human-mediated telepresence.

[lviii] AudiSoft server software enables clients to centralize expertise in support of both: teams of widely distributed, highly remote, and rapidly mobile field technicians equipped for wearable real-time videoconferencing; and large numbers of cameras for monitoring remote environments.
[lix] For low latency streaming of real-time multimedia through low-end variable bandwidth mesh networks.
[lx] Notably, AudiSoft's combined platform of rugged and hands-free hardware, customizable software, and server technologies are not deployed together as a wearable montage. In the major telehealth field trials (including *Tele-Assistance en Soins de Plaiis*) associated with their systems wearability is excluded.
[lxi] Funding partners, research partners, and governance-committee composition jointly selected a clinical setting for experimentation in parent-child pediatric follow-up services in *Clinique Médical Angus*. The project is newly retitled *My Digital Frontline in Healthcare*, which reflects how this project "allows parents to gather, keep and manage their child's medical information in one place" – online. (http://www.cefrio.qc.ca/en/projects-research-investigations/Digital-technology-health/my-digital-primary-health-care/)
[lxii] My research with Thought Technology Ltd crosses into the psychophysiology purviews of some current future-soldier programs. Avoiding conflict of interest obliges me to pointedly not detail future soldier psychophysiology capabilities here, except to say these capacities are currently underdeveloped for use in teleparamedicine writ large.
[lxiii] *FÉLIN* has been sold to several of France's strategic allies. *FÉLIN* began with demonstrations between 1997 and 2000, system definition and development from 2001 to 2007, and initial (and ongoing) deployment following first sales in 2009.
[lxiv] For example, while the *FÉLIN electronic jacket* subsystem integrates and distributes computer, radio, human-computer interaction, positioning, cables, and connectors, the *electronic jacket* remains a spoke-and-hub model, with a single, centralized, general-purpose computer. Similarly, the *Nett Warrior Samsung Galaxy Note2* smart phone enables hands-free voice communication via bone-conduction headsets and the standard body-worn radio as the sole communication gateway.
[lxv] These programs do include consideration for future modules in line with the *Nett Warrior War Fighter Physiological Status Monitor* subsystem (WPSM). However, these suites of wearable physiological monitors will require an updated model both formulated from, and supporting, qualitative studies and mixed-method research of operators in context as highly autonomous actors. Future-soldier systems are not fully congruent with teleparamedicine actors, who may individually and collectively subvert, resist and evade authority.
[lxvi] This offers benefits for collaboratively increasing workload capacity, ameliorating fatigue, detecting injury and reducing conflict among peers with possibly conflicting goals. Conflicts arise across a hierarchical community removing decisions from local actors and placing centralized and top-level interests before those of local representatives. However, if granted adequate authority, local agents embody unique and possibly invaluable discretionary powers to engage constructively with local jurisdictions, civil society, and affairs unfolding in real-time. Supporting paramedics in high-risk settings with psychophysiological augmentation obliges participation and consultation of paramedics in two-way dialogue, with multiple levels of command. Embodied human mediators' better (in comparison to solely machine based processes) leverage embodiment-oriented technologies for psychophysiological and environmental sensing, sensor fusion, context-awareness, and semi-autonomous or autonomic computing. Future-solider systems may inadequately support those high-value horizontal command structures enabling human-based computation to continuously update the parameters of telepresence interactions through parallel concurrent and long-baseline consideration of qualitative data.
[lxvii] These toolsets are assembled as combinations of stethoscopes, thermometers, blood pressure monitors, otoscopes, ophthalmoscopes, endoscopes, ultrasound and X-Rays visualization devices, heart/brain/nerve/muscle/skin electrophysiology monitors, brain/muscle electrophysiology stimulators, ventilators, and defibrillators.
[lxviii] However, *VSee's* successful adoption rate is largely attributable to its security, as its encryption is system wide, end-to-end, certified, and thus adoptable by governments, businesses and non-governmental organizations responsible for sensitive data.
[lxix] However, *VSee*'s versatility should not obscure its core architecture as a human-computer interaction for team collaboration based on combinations of visual displays, cameras, speakers and microphones. These generic audio-visual modes limit the body language and facial expressions to those transmissible

by video call. Those human factors not recognizable via 720-pixel high-definition video, hissing microphones, and warbling speakers are excluded. *VSee*'s collaborative documentation among specialist, nurse, and patient spans in-take forms, call routing, virtual waiting rooms, prescription, billing, scheduling, patient medical records, care plans, and document signing. However, while *VSee* may take its operators as caregivers or as patients, these telehealth tools do not aim for paramedic safety and are not seamlessly interoperable in high-risk settings. However, in the hands of skilled clinicians, patient-oriented telehealth tools may only be marginally enhanced by adding bidirectional paramedic-worn telepresence capabilities.

[lxx] WEHST's technical constraints include implicit co-design aspects perhaps incidental to all distributed computing networks.

[lxxi] Embodied cognition by artificial intelligence and robots draws on evidence-based, often ethological, understanding of human, biological and ecological instances of embodiment. Consideration of spoken and written language, and non-verbal communication, as types of embodied cognition are relevant for modeling technical aspects of how teleparamedicine and WEHST interface with paramedics. Human embodiment comprises: first, bodily aspects of motor system, perceptual system, and bodily interactions with the environment; and includes second, cognitive aspects of high-level constructs of judgment or reasoning about concepts and categories. Paramedics' tight coupling with WEHST toolsets and teleparamedicine systems facilitates self-regulation processes promoting goal-relevant actions in adverse environments. Paramedics' link with WEHST also embodies positive emotions promoting rapport during paramedic-to-WEHST and paramedic-to-specialist processes of qualitative and quantitative self-disclosure via monitoring and transmission of their psychophysiological states.

[lxxii] Subsumption architectures may be instantiated at multiple levels from within discrete electronic modules, among electronic modules (such as WEHST), within particular human-based computation relationships, among teleparamedicine participants, and across telemedical-ecosystems.

[lxxiii] Shapiro notes how subsumption architectures demonstrate Brooks' deep influence by Gibson's concept of affordances.

[lxxiv] In absence of a widely accepted unified definition of consciousness.

[lxxv] The possibility of positioning WEHST devices on both pilots and their external human cargo of paramedics and patients shows the significance of teleparamedicine in real-time decision making by human external transport system teams.

[lxxvi] This second stage of rescue also entails choosing among nearby landing sites, locating a hover-exit site, or, if it is the only way, using longline rescue with a helicopter external transport system.

[lxxvii] Al's teams include human external transport systems-qualified physicians and paramedics alongside search and rescue volunteers without advanced medical skills.

[lxxviii] Fine-tuning telepresence media production in perturbed environments is a situation where automatic media settings may fail. Wearable system operators experience cognitive, physical, and sensorial overload. For example, self-contained breathing apparatus (SCBA) is wearying for operators already wearing movement-restricting level-A chemical-biological-radiological-nuclear-explosive protective suits. Equipped thus, first responders are in a dangerous site for a maximum of 20-30 minutes before coming out. One pair of operators is in the danger zone while a second pair of operators stands by to rotate into danger.

[lxxix] WEHST orients its communication capabilities toward first self-stabilization processes of monitoring itself, its wearer, its proximal - and ambient - environments, and only then tracing and tagging the telecommunication spectrum.

[lxxx]This extends the local paramedics awareness by stitching together a whole-team situational awareness from multiple cameras, sensors, and expert supervisors. However, "There is value in the [human-mediated teleparamedicine] you described. I'm struck by the thought that you would need to have dispatch or command - a working protocol inside search and rescue units – where those resources that person that expert is back at a command-and-control centre. However, the way SAR [search and rescue] is staffed right now is so light." Sgt. Condly thought reducing paramedic cognitive load without adding onerous supervisory staffing levels may be possible. This would be accomplished by enabling nearby teammates in the field to provide on-site supervision of paramedics provides the benefits of lower latency and higher bandwidth.

[lxxxi] Augmented communication is needed by paramedics and search and rescue operators climbing, in confined spaces, or wearing chemical-biological-radiological-nuclear-explosive personal protective equipment, have both hands occupied. When paramedics hear something on their radios they require an instantaneous and non-verbal response. This could detect a team-mate falling over or falling down. For example, if paramedics do not have time to say anything, pre-arranged synthesized cues (auditory, tactile, and visual) may be analogous to shouting the word "falling." It could save paramedics' lives and limbs, and extend careers. The costs of these capabilities are wearing combinations of accelerometers or inclinometers. These inconveniences are offset by creating an auditory or visual feedback that means something to paramedics. Sgt. Condly illustrated the context: "In the climbing world the call "falling" is intuitive or "on belay". "Belay on". There are a few commands that just become rote: Falling. I would say that a tactile input while climbing is probably less likely than an auditory input. Falling. Everybody knows falling. You know what to do dutifully wherever you are; if you are an anchor-man, or if you are a belay man, you immediately get on your belay, so there's no more than a meter of a fall."
[lxxxii] The pilot's field of view is different from the emergency manager possibly on the ground – or even sitting beside them. Radio operations speed, simplicity, or clarity benefits from humans and on-the-body artificial intelligences in the loop taking turns and detecting when paramedics may not get their radio to work. Considering body posture as integral to closely-coupled communication narrows my research problem to communication with multimodal sensing and distributed computing capabilities.
[lxxxiii] Installing even a minimal teleparamedicine system of real-time monitoring creates a duty of care for the responding agency. This may include qualified, dedicated clinicians always available to monitor. For example, tracking overall fitness requirements and individual base levels of ground search and rescue operators may proceed as the person being remotely monitored by a clinician exits or enters a response scene. The field operator can carry their own baseline and frequently update their current physiological status to remote clinicians. Paramedics themselves are among the best-qualified clinicians to conduct this type of telehealth support across trades. A rescuer comes out of a rescue scene. They've done their assignment. They've rested for four hours. They return to the rescue scene, where they find British Columbia Ambulance Service waiting for them. Carrying a minimalistic monitor with them, they can store share, and update their personalized physiological "tracks" and trends. Monitoring British Columbia Ambulance Service paramedics' psychophysiology heart, muscle, neural, respiration and metabolic processes are synchronous with interventions to rest, breathe, hydrate, eat and debrief.
[lxxxiv] Rene and Ian both described the first-responder psychophysiology profiles as useful from the very start of training. For example, current best-practices in the Vancouver region apply individualized baselines in the field where fire departments start their four-day shift. They begin their work shift by taking vital signs on each other, writing it down, and putting it in their pocket. When they later arrive at a fire, a BC ambulance paramedic compares their recorded baseline to their current state - before and then after the firefighter goes into a fire. However, psychophysiological evaluation is a specialized skillset needing to be taught. It obliges setting up proper systems for teams to communicate with doctors who have some understanding of context. Rene described a "win-win-win" situation where a commander worried for an individual gets experienced medical opinions accounting for, in Rene's voice of a hypothetical doctor: "What's he been doing? Is he on his second bottle of oxygen? Who is he? Does he have a medical history? What's the history? I don't like the flag of his heart rate or the fact that he's got a couple palpitations now. There's something else going on. Let's remove him."
[lxxxv] Wearable computers may integrate physiological and environmental sensors into wearable suites, and may include blast and trauma detectors, activity and fitness trackers, navigation and targeting, CBRNe detectors, GPS, etc. Wearable computing systems may plug into vehicle systems, link wirelessly in squad-level intranets, or form long-range networks.
[lxxxvi] For some emergency managers, equipment inventory may be equally important to knowing how much air is left in their crew's tanks.
[lxxxvii] Advanced monitoring of team dynamics may make both hiring and procurement more selective. Orienting personnel and matériel toward specific tasks ahead of the actual event is possible if teleparamedicine equipment helps teams train, find their shortcomings and weaknesses, and work as a cohesive unit to fill those gaps together.
[lxxxviii] Ian explained that WEHST's proposed on-the-body ecosystem of interoperable heterogeneous modules has similar database management and security expenses to bare-bones audiovisual telehealth

delivered by an off-the-shelf camera and radio. The economic costs and benefits of wearing "black boxes" to safely conduct and evaluate teleparamedicine research in search and rescue chemical-biological-radiological-nuclear-explosive settings may be measurable in terms of balancing resource allocation between people and automation.

[lxxxix] The legal ramifications of producing, storing and controlling access to teleparamedicine media orients it toward early adoption for training environments. Reviewing video (and other media) produced during training may be useful for instructors days or weeks following a training scenario. Notwithstanding requirements for and secure transmission of patient records, video used in real-time teleparamedicine patient care may also be useful to access later. How, and by whom, video and information about video is accessed is fraught with tensions between confidentiality and access to information. Inevitable freedom of information (FOI) requests and concomitant data-sharing infrastructure make legality of production, storage of, and access to, teleparamedicine media a major design constraint. Ian's response to proposed paramedic-worn videoconferencing capabilities illuminates this:

"Collecting video makes it FOI'able. Now do we have an obligation to host an FTP site? Where if you wanted to know "Jeez, why did my rescue take so long?" Okay you FOI all of the information, and now we've got video, what do we do with that if on that video the subjects name is used, and the subject isn't the one doing the FOI – maybe a media outlet? Now how do we redact that name? The tool would have a bigger application in the training environment."

[xc] Data and cost-sharing partnerships of government agencies' practice and institutional research develops national or international databases that could pull disparate infrastructure, research communities, funding models and databases together.

[xci] Research participants also advance understanding of whole life-cycle issues of device adoption, regulation, service, and disposal. Some participants address physical issues of manufacturing, materials, processes, and economic issues of R&D, manufacturing, marketing, and sales. For example, some informants know the pros and cons of telecommunications, others know field-serviceability requirements of equipment, and others know how team learn to use new tools.

[xcii] Combinations of voluntary physiological signals appropriate for control of radios may be collected from electromyography, electroencephalography, electrooculography, respiration, and skin conductance sensors. Many other types of wearable sensors are also appropriate for this application.

[xciii] Dr. Inniss describes how WEHST's non-invasive sensing increases the wearability challenge:

"It's an interesting field of study, because by definition, being non-invasive you are then exposed to environmental factors in SAR [search and rescue] and that's the unique thing about it. Whether it's the marine environment with salt, moisture and humidity, or the winter environment with temperatures and icing. As soon as it becomes non-invasive it usually friggs up. It usually does. When you brings a subject in, and the ambulance driver picks them up on the tarmac here, and says "why didn't you put an IV in?" and its minus 12 out. Have you ever tried to handle IV tubing at minus 12? They just don't have that idea that it's impractical and impossible – so it's a unique setting for sure. It deserves a unique focus."

[xciv] Sgt. Condly noted the value of such technology in the *Canadian Armed Forces* if aligned with work by the *National Biological Chemical Warfare Centre*. Technology transfer is particularly cultivated if the teleparamedicine system's primary architecture has inherent expansion capabilities through "snap-on" peripherals adapted to the immediate conditions.

[xcv] Sgt. Condly indicated that he would like to remove his radio from his chest where it sits on top of harnesses as a "fouling hazard". He would like his radio to be a plug-in module positioned in a free and protected area on the side of his chest below his armpit.

[xcvi] Little short of full compatibility of core teleparamedicine garments with the diverse technicians' personal protective equipment of a wide swath of search and rescue and chemical-biological-radiological-nuclear-explosive trades will engage unions or institutions to readily adopt WEHST. Wider adoption may support cross-institutional training, particularly of paramedics, which would lead to cross-pollination at the level of hardware, software, and care protocols or guidelines.

[xcvii] Research participants also advance understanding of whole life-cycle issues of device adoption, regulation, service, and disposal. Some participants address physical issues of manufacturing, materials, processes, and economic issues of R&D, manufacturing, marketing, and sales. For example, some informants know the pros and cons of telecommunications, others know field-serviceability requirements of equipment, and others know how team learn to use new tools.

[xcviii] Paramedic-generated media appropriateness is tied to emergency managers' feelings for – and assessments of – paramedics' levels of experience. Live-feed media are valuable if managers understand the competency and perspective of the paramedic behind the camera. Dunc describes how teleparamedicine may allow managers to speed up, or reasonably improve the safety of, the rescue. "The system we have now isn't really a problem. But again, having live feed isn't a bad thing because dealing with volunteers – they're not in the situation all the time judging weather and stuff like that. And a lot of times they might be on the cliff there and I say "how's the weather?" and a pictures worth a thousand words. "I can see you", or, "it looks good", "it looks bad", or, "about half-a-mile." some people just have a problem judging that. As they gain more experience some are better than others."

[xcix] Sharon and Al both identified how teleparamedicine becomes relevant by fitting into chemical-biological-radiological-nuclear-explosive settings by physically compressing pedagogical and documentation capabilities into a small-enough form factors to be widely used. Teleparamedicine usability needs to meet daily use by paramedic, military, and fire service professionals, or sporadic use by volunteers; and constantly monitoring those career operators with helicopter external transport systems, chemical-biological-radiological-nuclear-explosive, search and rescue, and paramedicine qualifications. Adding additional equipment requires offsetting increased physical or cognitive demands against short-term and long-term benefits to paramedic and patient health, paramedic or remote specialist scope of practice, documentation, and communication.

[c] Helping teleparamedicine operators cope with psychophysiological stress requires emergency managers and team leaders to act as mediators of whole-team equilibrium. The liabilities and benefits of always-on surveillance must be balanced against the appropriateness of team stress-coping mechanisms such as encouragement or support in real time in response to stress cues.

[ci] Sgt. Condly makes detailed reference here to two incidents in the prior six months in British Columbia involving a total of three paramedic deaths caused by carbon monoxide and carbon dioxide poisoning in enclosed spaces. He explicitly declares these scenarios show there is value in simultaneous physiological and environmental monitoring.

[cii] Higher-rated personal protective equipment generally induces more stress but is required for initial evaluation. Monitoring operator physiology, personal protective equipment microclimates, and ambient environments ties back into control of radio communications.

[ciii] My initial overarching designs were of monolithic, complicated, fully integrated teleparamedicine garments addressed a multitude of constraints. These began as complex integrated designs with little modularity, scalability and adaptivity. This focus on the environment designed the device from the outside-in. Over time these were decomposed and designed into the fabric of teleparamedicine and WEHST. WEHST design commenced with an extensive, cluttered, awkward, restrictive garment and arrived at a material substrate for a platform composing a fabric allocating and partitioning human-mediated teleparamedicine actors into a textile of computation. Through continuous modeling processes, system-level architecture of procedures and specifications emerged. Iteratively developing these models removed features until solely ANT and physical black boxes and fabric remained. This computational fabric comprises eight interleaved families of wearable computing devices emerging across multiple scales of: electro-mechanical elements; robust yet pliable components; highly specialized yet interoperable products; a generalizable yet bespoke system; personalized yet shared experiences; and enduring processes of transformation. The computational textile of COMmand, WEHST, and teleparamedicine constitute human, biological, analog, and digital hybrid computing writ small.

[civ] Super wicked problems (introduced by Kelly Levin, Benjamin Cashore, Graeme Auld and Steven Bernstein in a 2007 conference paper, and a 2012 article in *Policy Sciences*. These are wicked problems with the additional complications of being time sensitive, poorly coordinated, conflict of interest, and disregard the future.

[cv] Fabric computing constitutes the assemblage of a computing fabric comprised of interwoven connections among distributed nodes of computation that collectively describe a 'fabric' when regarded from a distance.

[cvi] Hands-voice-speech-free wearable radio operators are, to apply an "amateur radio" term, 'black box operators' in the sense of operating without having or requiring good understanding of how these decentralized and dynamically self-reconfiguring devices are built, operated or repaired.

[cvii] Paramedics in chemical-biological-radiological-nuclear-explosive settings are garbed in protective suits, breathing apparatuses, masks, heavy gloves and boots, and often helmets. Chemical-biological-radiological-nuclear-explosive personal protective equipment generates extremely stressful microclimates *and* cumulative sensory, physiological, biomechanical, and psychological impairments.
[cviii] I gradually improved the fit and feel across scales extending from COMmand on the body, to WEHST-based human-mediated teleparamedicine across sites, and towards wider teleparamedical ecologies. Fit and feel were parameterized in terms of size grading, specialization, personalization, changing environments and microclimates, hygiene, serviceability, upgradability, and manufacturability.
[cix] WEHST fits two-way, real-time, paramedic-in-the-loop telepresence inside the technical envelopes required for high-risk first-response scenarios. However, the first-responder community are conservative in regards to materiel in general. This community are particularly resistant to changes to those garment and equipment montages developed over decades to safeguard paramedic well-being.
[cx] Wearable telepresence is only valuable if consistently granting mission critical capabilities adequate for wide-ranging and mutual mediation between remote specialists and paramedics in the field.
[cxi] WEHST's modular granularity and range of scalability is tunable to suit systems range of adaptation to suit their operators and environments while simultaneously responding to mutual adaptations of operators and environments.
[cxii] Thus, WEHST's normal-use conditions furnish an environment for developing software such as genetic algorithms. Software is refined through, and further facilitates, the adaptation and co-evolution of individual agents and particular network configurations.
cxiii WEHST gives a practical level of interoperability to accommodate differences among regional and international organizations and locales. Each community of practice requires multiple telecommunication systems, uniform systems, load-bearing harnesses, and personal protective equipment. Interoperability significantly reduces expenses by providing a single system able to adapt to variations in matériel configurations. WEHST's myriad system configurations work in concert with many different layers and stages of each individual team's matériel deployments. WEHST interoperability may reduce outlay of financial, and human, and ecological resources of paramedicine systems continuously maintained and reconfigured by paramedics. WEHST also reduces expenditure of resources for orientation, training, and continual recertification in the use of such systems.
[cxiv] Wolfgang Jonas shares an assessment offering partial guidance for situating design-led research: "Design is everywhere - but not everything. Design cannot be substantiated scientifically. Making does not aim at generalised knowledge, but at the functioning of the made. Design has no paradigmatic core, but is a "groundless discipline".[…] A meta-model of science and design has been sketched. Both have a common fluid base: the hybrid. The network morphology provides legitimate feedbacks and self-references in the development of theories, renders the dynamics of theories in design describable with changing attractors (static, cyclical, chaotic). The quasi-objects / artefacts are the agents of knowledge production. This permits us to recognise the sciences as extreme positions in the mediation process." Jonas, Wolfgang. The paradox endeavour to design a foundation for a groundless field. Hochschule für Kunst und Design Halle, Germany. December 2000. Downloaded June_2012 from http://home.snafu.de/jonasw/JONAS4-54.html
[cxv] Moravec's paradox is a finding by robotics researchers, that the motor and sensory skills of operating a robot's body and sensors are computationally intensive, while high-level problem solving requires little computation.
[cxvi] Administrative scalability is the ease with which a single distributed system is shared by an increasing number of organizations or users.
[cxvii] Functional scalability is the ease with which a system enhanced by adding new functionality.
[cxviii] Load scalability is the ease with which the distributed parts of a system can be added, removed, or modified to accommodate changing loads or inputs.
[cxix] Geographic scalability is the ease with which a system performs well in either locally concentrated or globally distributed assemblages.
[cxx] While geographically distributed authority is endlessly disputable among human-mediated teleparamedicine stakeholders.
[cxxi] Generation scalability is the ease with which a system scales up by incorporating new generations of components.

[cxxii] Heterogeneous scalability is the ability of a system to use an open computing/software architecture able to add, upgrade and swap components supplied by multiple vendors.
[cxxiii] For example, tracking posttraumatic stress disorder (PTSD) triggers emerge through physiological and environmental context awareness. A heart rate signal plus skin conductance plus body temperature correlates beat-by-beat and within each beat.
[cxxiv] Participant experiences of self – or selves – reflexivity vary depending on how non-local and non-unitary co-actors share the position of a particular human-mediated teleparamedicine field operator.
[cxxv] Large-scale heterogeneous organisations are excluded because they may have less effective means to communicate their interests to policymakers and technology providers to ensconce HMTPM regulation and WEHST standards within formal public agendas.
[cxxvi]Taxonomies of mobile telehealth material culture, grounded in complex adaptive ecosystem perspectives, may situate processual models of teleparamedicine in a 'post-ecology world'. Ecology, as both a human cultural production and material phenomena outside of culture, includes the people, technologies, and organisms in teleparamedical ecologies. Teleparamedical ecologies may be simultaneously reductively modelled and situated in non-reductive 'ecology-in-place' worlds.
[cxxvii] WEHST is proposed as a research-ready research platform premised on ubiquity on- or very near – the body. Proximity to bodies in motion supports evidence-based decision-making for: research design; budgeting and purchasing; team selection, training, and politics (exacerbated by wearing functional lie detectors); ethical, regulatory, and legal compliance; personalized, team-oriented, and context-sensitive configuration with other tools; and selecting and adapting from a host of possible sensor modalities.
[cxxviii] WEHST is readily geared to accommodate requirements for intellectual property development and management, manufacturability, production design, component and process sourcing/selection/ buying, inventory management, marketing, sales, shipping, support services, strategic partnerships, and remediation.
[cxxix] Complex adaptive systems (CAS) are instances of complex systems where partially connected sub-structures emerge to enable adaptation to environmental perturbations, and enable its continuity as a macro-structure.
[cxxx]Paramedic's embodiment may be distributed throughout teleparamedical social and technological networks. The entanglements and distribution of teleparamedicine boundaries may preclude teleparamedics bodies constituted as other than fluid margins within material semiotic networks.
[cxxxi] Furthermore, human-based computation wearability permits extensive "natural human computation" (Estrada and Lawhead, 2013) by leveraging extant computationally significant human behavior to extract work without too rapidly or greatly adding to the human cognitive load.

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Appendices

10.1: ANT actors in teleparamedicine

These complex relationships are impossible to frame through reductive methods without investing hundreds of millions of dollars in research and development by multidisciplinary teams with academic, industry, and government partners. However, as ANT's processuality excludes methods per se, its approach gives inscriptions of ethnographic contact with actors as an alternative to more reductive research procedures. My research and design specification setting are guided by understanding how inscription processes create textual and multimedia artifacts to advance actors agendas. Inscription of Paramedic and COMmand co-performance embodies inscription processes. Through inscription of media artifacts COMmand serves paramedic performance as a teleparamedicine focal actor translating many types of actors into a whole. However, ANT's espousal of teleparamedicine actors as partial and contingent delineates industrial design of actors as open-ended within and across levels of COMmand module, WEHST system, and teleparamedicine experience.

COMmand design is both an inscription of relationships among, and performs as an inscription device on behalf of, teleparamedical actors including humans, texts, technical objects, telemedical ecosystem processes, and economies.

First, human actors are intimate paramedic operators; proximal patients, colleagues and pilots; distal specialists, relay operators, network administrators, researchers, developers and designers.

Second, "texts are actors" (Linden and Saunders 2009, P149) as electronic health records (EHR), drug protocols, weather forecasts, and all media files, metadata, firmware, and sensor readings. Most texts today are nominal human-computer interactions (HCI) which "rework and extend the network." (Callon 1991, P136)

Third, technical objects are actors. Teleparamedicine gives opportunities for self-expression to personal protective equipment, radios, medical instruments, ambulances, helicopters, airplanes, satellites, and telecommunication networks. COMmand may be augmented with an extensive ecosystem of WEHST modules, radios, and peripheral sensors.

Fourth, telemedical ecosystem processes are actors spanning micro, meso and macro scales. Micro-scale actors include communities of pathological, benign, and beneficial organisms. Micro-scale actors are processes of matter in-and-out-of place including chemical and mechanical adhesion, catalysis, disinfection, and corrosion or abrasion. Meso-scale actors include those human bodies in collision and in concert during teleparamedical assessment, care, and transport. Macro-scale actors emerge from interplay among: seasonal and diurnal cycles; ecological, climactic, geological, and meteorological phenomena; and wider effects of activities including energy production, agriculture, mining, fishing, forestry, and urban and industrial infrastructure development.

Fifth, economies are actors. Economies, as mediums of exchange, are rather nebulous figures for ANT to describe, as empirical aspects of actor-networks of economies may be over-emphasized, “[…] at the expense of analysing how such empirical contexts are also internally mediated through abstract capitalist processes such as that of surplus value extraction.” (Roberts 2012, P1) However, considering actors along short and long timescales shows profits include quality of life resources preserved. Resource conservation happens by preventative care, early interventions, personalized care, follow-up, continuing care, and home care. ANT offers means of communication these costs and savings otherwise difficult to portray. Furthermore, ANT-grounded depunctualization (Callon 1991, P149, 152) of economic actors reveals externalized costs of business models as actors from ecological economics and environmental economics who link ecologies and human economies. All of these actors focus via COMmand, because COMmand is a hub for teleparamedicine adaptation processes by conveying and collating feedback among actors.

10.2: Sample Consent Form SPF UH2010-102

Summary Protocol Form Sample: CONSENT FORM TO PARTICIPATE IN RESEARCH

Participants will be given two copies of the consent form – one to keep, and one to sign and return to the researcher.
If participation is to be strictly off the record this consent form is optional.

Name: ___________________________________
Date: _____________________

CONSENT TO PARTICIPATE IN:

Practice-Oriented Design Ethics Research of Computational Textiles in Teleparamedicine.

This is to state that I agree to participate in a program of research being co-investigated by Andre' Arnold, Ph.D. student, of the Special Individualized Programs of Concordia University. Office address: 5120 Rue Garnier, Montreal, Quebec, H2J 3T2; Telephone number: 514-358-1556; Email: gilham_arnold@hotmail.com.

This is doctoral research supervised by Dr. Kim Sawchuk, a Concordia University, Communication Studies Associate Professor; Room L-CJ 4431; Phone 848-2424 ext 2557; Email - kim.sawchuk@sympatico.ca.

A. PURPOSE

I have been informed that the purpose of the research titled "**Computational Textiles in Teleparamedicine: Practice-Oriented Design Ethics"** is as follows:

Telehealth uses telecommunication technologies to provide health care services to patients across distances.

This research investigates how and why consideration of research ethics may transform industrial design practices of developing telehealth technologies based on computational textiles. The scope of this particular industrial design research practice is restricted to paramedic-worn technologies enabling telehealth. By discussing the concrete ethical dilemmas of paramedics and telehealth policy-makers, this research seeks to understand how the design of telehealth tools is shaped by the ethics of their use.

PROCEDURES

Participants in this survey will be asked to answer verbal questions about the subjects of telehealth, internal medicine, ethics, and design. It will be clearly indicated in any published materials resulting from this research that the outcomes do not necessarily reflect the views of the research participants. If participants prefer they may remain "off the record". If participants object to their responses being recorded electronically, they may choose for their responses to be recorded on paper, or remain entirely unrecorded. At the interviewee's discretion, responses to the questions may be recorded with a portable digital audio recorder operated by the principal researcher. Participants may choose to give brief or lengthy answers to any of these questions. The number of questions a participant may be asked will be varied to match the planned interview length. Participants will not be paid.

C. RISKS AND BENEFITS

This research is intended to constitute low potential risk to research participants' professional reputation.

The benefits of participation include:

- A primary benefit of this research is the development of ethical design and policy guidelines for mobile telehealth products in real-world scenarios.

- Secondary benefits of this research include creation of new ethical and technical knowledge relevant to non-design domains. Paramedic telehealth products enhance human-centered research practices of: Security, Sociology, Anthropology, Justice, Journalism, etc.

D. CONDITIONS OF PARTICIPATION

Please understand that the data from this study may be published. Participants may choose the degree of confidentiality that they are comfortable with from the list below. Confidentiality will be maintained for the duration of the research. You may change your indicated preference of degree of participation at any time during or after the interview, and prior to publication. Following publication, electronic or tangible media transcripts will be surrendered, or destroyed, at the request of the participant.

Do you consent to having your participation recorded by the interviewer using a digital audio-recorder?

Yes O No O

Would you prefer an interview length of: Fifteen minutes, Thirty minutes, Forty-Five minutes, or as long as is necessary?

15 O 30 O 45 O As is necessary O

Please check the box next to the degree of confidentiality that you are comfortable with:

Participation to be off the record.
This consent form provides documentation of the participants choice to remain off the record. O
If you object to being recorded responses may be recorded on paper. O
You are willing to be directly quoted by name and title in any published materials. O
The context of quotes or attributions included in materials intended for publication will be verified with, and approved by, the original contributor before publication. Quotes or attributions in the Concordia University Doctoral thesis will not be confirmed with the original sources unless the thesis is accepted for publication in whole or in part.

D) Be directly quoted with title attributed, but name withheld in published materials. O
E) Be directly quoted with name and title withheld in published materials. O
F) Not be directly quoted, but name and title (and status as participant) may be published. O
G) Not be quoted, and name and title may not be published.
O

H) You are willing to give permission at a later time to be directly quoted by name and title in any published materials, if and when you see the results first. O

I understand that I have chosen my participation in this study to be either CONFIDENTIAL (i.e., the researcher will know, but will not disclose my identity), or NON-CONFIDENTIAL to a degree that I am comfortable with (i.e., my identity will be revealed in study results):

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print)

SIGNATURE

If at any time you have questions about the proposed research, please contact the study's Principal Investigator Dr. Kim Sawchuk, Concordia University, Communication Studies; Room L-CJ 4431; Phone 848-2424 ext 2557; Email - kim.sawchuk@sympatico.ca.
If at any time you have questions about your rights as a research participant, please contact the Research Ethics and Compliance Advisor of Concordia University, at 514.848.2424.x 7481 or ethics@alcor.concordia.ca

10.3: CIAM -funded Intelligent Textile Computer Architecture workshops:

Short description:

My Ph.D. studies examine the intersection between industrial design practice and ethics. The practice component of my doctoral research investigates the industrial design of intelligent textile based wearable biomedical instruments for the delivery of telehealthcare communication, diagnostic, monitoring, and therapeutic services. The theoretical component of my thesis is dedicated to the creation of new knowledges for designing ethical tools, and designating ethics as a tool in both media arts research creation and design.

Conceptual and procedural description of the project:

My Ph.D. research combines new media arts technological research, from within the field of industrial design, with ethnographic research. My studio practice is the design of novel wearable biometric communication media. A central technical challenge is developing innovative intelligent textile computer architectures integrating textiles, computing, and biometric sensing components into robust, reliable, intelligent textiles.

To address this technical challenge, I propose a series of design workshops investigating the topic of Intelligent Textile Computer Architecture. 15 workshops, lasting two hours each, will be hosted in Hexagram studios within Concordia, UQAM, UDM, and McGill. Two paid professional assistants with expertise in areas of intelligent textiles and computer architecture will be hired (at $15/hour) per workshop. Professional assistance will be in both French and English. These workshops create opportunities for paid expert consultants and unpaid participants to come in and work together on a single day – as a means of mutual technical problem solving.

These workshops permit me to: define, describe, design, and develop multiple iterations of intelligent textile computer architectures with the assistance of paid professionals; train unpaid workshop participants in the areas of intelligent textiles and computer architecture; and conduct ethnographic study of design processes of both paid and unpaid participants.

Technical description of the project:

These design workshops will produce commercially viable Intelligent Textile Computer Architectures for real-world applications, using existing technologies, materials, and processes. Guest speakers and presenters from the design, media arts, and computer science communities will be invited to discuss both the technical and conceptual challenges and opportunities of intelligent textile and computer architecture design and development.

The proposed "Intelligent Textile Computer Architecture" workshops will emphasize concept design and development through dialogue, sketching, and prototyping. These structured workshops will include myself (principle investigator), a small number of paid professional assistants, and openly invited participants from the broader academic and artistic communities. Workshop participation will include dialogues, interviews, and performances. No fees for participation will be demanded from any of the participants. Formal workshop documentation will be produced primarily by the principle investigator – and by the professional assistants and invited participants. Documentation will include: written notes, drawings, prototypes, 3D CAD models/animations, surveys, photographic documentation recorded audio, and recorded video.

Describe how the project is artistically or technically innovative in the field of new media arts:

CIAM is an excellent example of the interdisciplinary spirit which motivates my Intelligent Textile Computer Architecture workshops research project. This project is similar to the Techwatch 2004 watch by Christine Keller “Nomadic Computers, Digital Prosthetics, Accessories and Environments”

These workshops will be informed by contemporary – and emerging – theoretical dialogues considering postphenomenology, material hermeneutics, complex systems theory, social neuroscience, and design ethics. These workshops enhance the technical and commercial feasibility, and transferability, of my ongoing SIP Ph.D. industrial design studio research into intelligent textiles for biomedical diagnostic, monitoring, therapeutic, and communication applications. These workshops are based on the premise that intelligent textile computer architectures are complex adaptive systems performing as multimodal arrays of dense patterns of sensors and emitters (sound, light, pressure, motion, temperature, electromagnetic, etc…). These intelligent textiles must be robust enough to perform well in real-world telehealthcare scenarios.

As the principle investigator, I feel I am qualified to achieve meaningful research results through these workshops based on: my ongoing academic and professional focus on industrial design of biomedical technologies; a long-term interdisciplinary focus on neurobiology and sports physiology; and training and experience with design ethnographic methods in academic research and professional practice.

10.4 Moravec's paradox:

Hans Moravec articulates the phenomena underpinning the early successes of embodied and situated approaches to artificial intelligence and robotics is known as Moravec's paradox. He worked in the 1980s in parallel to Rodney Brooks and Marvin Minsky to understand why, and answer how, in artificial intelligence research,

> The hard problems are easy and the easy problems are hard. The mental abilities of a four-year-old that we take for granted – recognizing a face, lifting a pencil, walking across a room, answering a question – in fact solve some of the hardest engineering problems ever conceived. (Pinker 1994)

High-level reasoning requiring very limited computation resources – are in stark contrast with low-level sensorimotor skills demanding vast computational resources. Moravec explains how we underestimate the complexity of processes we perform easily, which have evolved through natural selection over billions of years, and of which we are mostly unconscious (In absence of a widely accepted definition of consciousness.). Simultaneously, we are acutely aware of, and attribute great refinement to, recently acquired simple abilities such as abstract thought processes we perform poorly. (Moravec 1988) This is a basis for designers seeking to model and reverse-engineer human or non-human biological phenomena.

> Encoded in the large, highly evolved sensory and motor portions of the human brain is a billion years of experience about the nature of the world and how to survive in it. The deliberative process we call reasoning is, I believe, the thinnest veneer of human thought, effective only because it is supported by this much older and much more powerful, though usually unconscious, sensorimotor knowledge. We are all prodigious Olympians in perceptual and motor areas, so good that we make the difficult look easy. Abstract thought, though, is a new trick, perhaps less than 100 thousand years old. We have not yet mastered it. It is not all that intrinsically difficult; it just seems so when we do it. (Moravec 1988 P15-16)

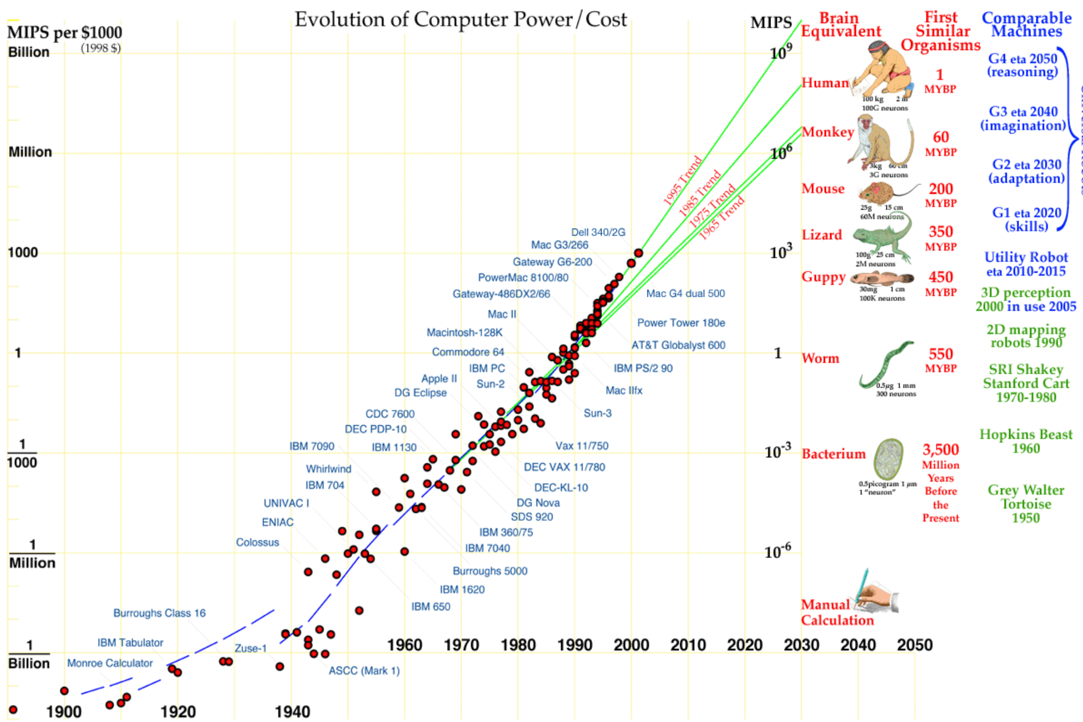

Figure 10.1: Diagram shows Moravec's Paradox. Image downloaded June 2014 from https://www.frc.ri.cmu.edu/~hpm/talks/revo.slides/power.aug.curve/power.aug.html

Moravec's paradox is thus a tool for inverting assumptions about intelligence, whereby refined and robust intelligence is embodied and embedded. While inversely, abstract intelligence is poorly refined, badly defined, only partly understood as correlated with embodiment, and rarely considered in an extended setting of being what "highly educated male scientists found challenging." Perhaps abstract intelligence is an epiphenomenon of cultural evolution (Brooks 2002, P36). The contribution to particular design projects to understanding evolution and embodiment is by reciprocally linking to real-world applied intelligence. The immense resource human embodiment, environmental situatedness, and extended cognition offer to technology design projects obliges considering human beings as a technology not to be underestimated.

10.5 Pentti Haikonen's neural-network theories of artificial consciousness:

Pentti Haikonen is a Finnish researcher and author applying neural-network theories of artificial consciousness to development of practical design guidelines for non-numeric approaches to autonomous robots through artificial associative neuron architectures. Haikonen cognitive machines are prospectively capable of achieving his process-oriented view of artificial consciousness, which he considers a cognitive architecture for robotic brains distillable as,

> "[…] the system architecture of the complete cognitive machine, the 'robot brain'. This machine is not a digital computer; instead it is a system based on distributed signal representations that are processed by associative neuron groups and additional circuits. This system is embodied, it has sensors and motor systems and it utilizes meanings that are grounded to the percepts of environment and the system itself, both the body and the 'mental content'." (Haikonen 2007, P8)

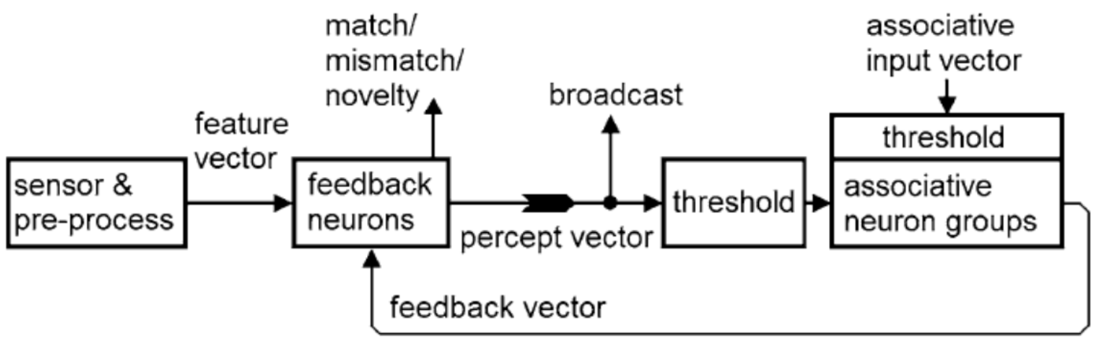

Figure 10.2: Diagram shows Haikonen Perception/response loop module. (Haikonen 2007, P161)

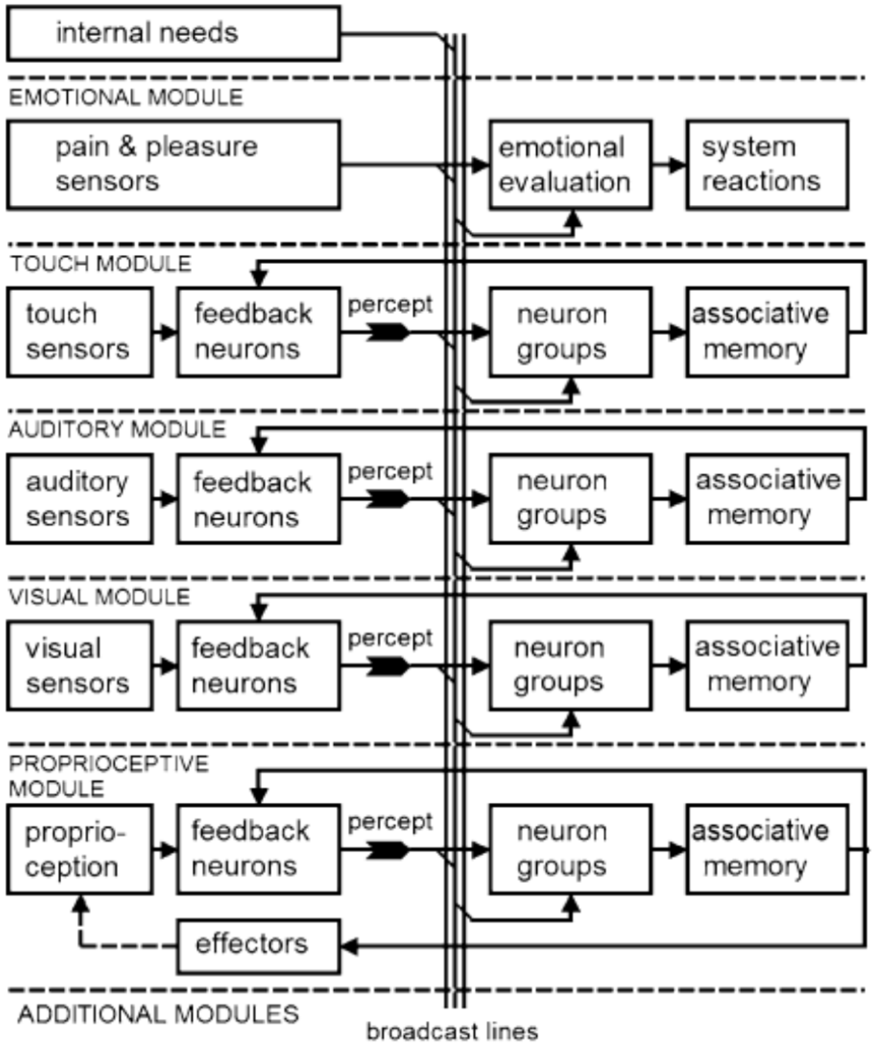

Figure 10.3: Diagram shows Haikonen cognitive architecture. (Haikonen 2007, P160)

Haikonen's work is pertinent on multiple levels of WEHST and teleparamedicine design, despite not being fully validated because he is concerned with emergence of artificial consciousness spontaneously by appropriately neuromorphic architectures. These artificial-consciousness criteria are relevant to my endeavor to render robust, stable, and coherent decentralized systems. The desired resilience is at the levels of discrete WEHST modules, on-the-body human-based computation toolsets of WEHST, and wider teleparamedicine systems. Haikonen's model of machine consciousness is built on an explicitly modular architecture comprising,

> ”Sensory preprocessing circuits that derive distributed representations from sensors, very large number of introspective feedback loops that detect sensory information and broadcast it to other loops, associative cross-coupling of these loops, attention control via large number of variable thresholds..” (http://personal.inet.fi/cool/pentti.haikonen/. Accessed May 2014)

Multiple levels of hardware, software, paramedics and wider teleparamedicine relationships, this architecture models a means of scaling a coherent (self-stabilizing) system from the bottom up, to achieve an appropriate minimum level of complexity required to fit a continuum of architectures. A range of organizational structures span from "simple reflex," "simple reflex with meaning," "perception with meaning and associative memory," "perception with associative memory and report" to a robot who "perceives itself perceiving." This spectrum of complexity is nominally hardware-based and involves no specific circuits supporting emergence of the consciousness emerging at one end of this spectrum. Haikonen proposes consciousness is a "content level way of operation" of inner feedback, and not a subsystem circuit constituting a homononculus-like detached observer. (http://personal.inet.fi/cool/pentti.haikonen/. Accessed May 2014)

My goals of WEHST reflexivity, paramedic-WEHST mutual subsumption and human-mediated teleparamedicine system coherence are contingent on achieving some degree of self/selves transparency of the system at multiple scales. Subsequent black-boxing of these entities at various scales constrains their percepts and thinking to the real world confronting them at particular junctures – without the distraction of the signal patterns of the carrying medium. Haikonen's concern with the transparency of carrier mediums is congruent with ANT concepts of black-boxing and translation. Transparency is enacted as telepresence among teleparamedicine associations, whereby signal modulations within relationships "are about something," not merely changes in the mutual associations of actants. Haikonen's autonomous robots are embodied in accordance with generally the same processes Brooks and Moravec's surmise to be "intelligent" without "programs and numerical representations of information." (Haikonen 2007) Non-numerical, analog robots utilize the Haikonen "associative neuron" to build associative neural networks capable of executing non-computable functions by applying his basic hardware building-block for operating in dynamic and partly apprehended situations. (Haikonen 2007, P43)

Haikonen's artificial-neuron component and attendant perception/response feedback loops scale up to a system-level architecture of decentralized discrete autonomous modules (Haikonen 2007, P180), from which consciousness emerges. This is relevant to human-based computation coupling within teleparamedicine settings in which paramedic and WEHST have parallel capabilities for: first, utilizing "meaning, context, and inner models" of exterior and interior contexts to understand ambiguous stimuli by use of human-based computation for mutual support and signal processing; and second, in cases where only context is available and "when no true features are perceived at all," (Haikonen 2007, P71) a human is needed to give support to WEHST via distinct capabilities of "top-down processing." Decades of further development are required for autonomous robots to have adequate faculties to perform even remotely close to true cognitive machines.

10.6 Pertinent Research Creation projects:

My work is also informed by telepresence research and art projects showing the value of wearable telepresence as a research mode.

Wearable Absence by Barbara Layne's Studio subTela combines psychophysiological sensing with telecommunications and electronic textiles. While her project has some parallels in the art world, few projects approach the level of sophistication of her decades-long methodical investigation of electronic textile substrates.

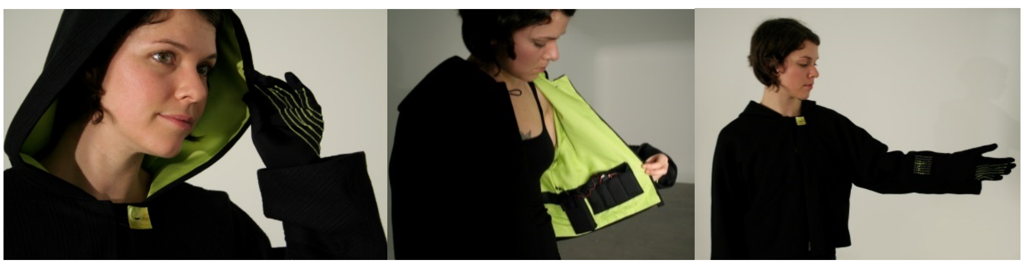

Figure 10.4: "*Wearable Absence*" Project by Barbara Layne's Studio subTela. http://www.wearableabsence.com/#/home and http://subtela.hexagram.ca/Pages/WearableAbsence.html

Eduardo Kac's *The Telepresence Garment* is a notable piece of wearable telepresence art, meriting consideration of its 1996 historical and political context.

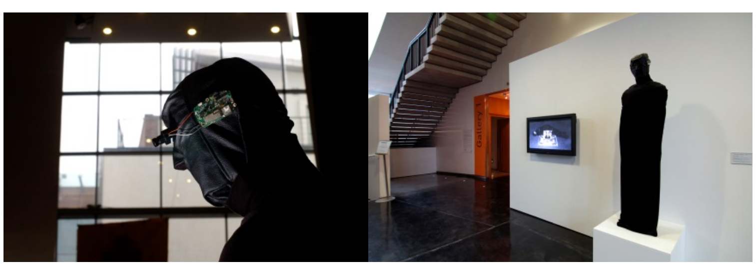

Figure 10.5: Photomontage shows Eduardo Kac's "*The Telepresence Garment*". Accessed May 2014 from: http://www.fact.co.uk/projects/sk-interfaces/eduardo-kac-telepresence-garment.aspx; and, http://www.fact.co.uk/media/6194847/Telepresence%20Garment2.JPG

"The Telepresence Garment contains telecommunications technology that allows the user to be remotely guided through an integrated webcam and a speaker. The garment becomes a second skin of fabric that restricts the movement of its wearer. Through wireless communication the 'other' takes control of the individual's perspective.” (Accessed May 2014 from: http://ekac.org/)

Steve Mann’s decades of extensive research are firmly ensconced in the wearable telepresence research realm and shows the relevance of sousveillance – including psychophysiology – to telepresence.

Figure 10.7: Photomontage shows Steve Mann Wearable Computing. (http://en.wikipedia.org/wiki/Steve_Mann)

The *Tele-Actor Project* was a 2000 to 2002 wearable telepresence computer ensemble for broadcasting live video and audio to remote operators via the Internet to explore telepresence and group dynamics.

Figure 10.6: Photomontage shows Tele-Actor Project. (Accessed May 2014 from: http://www.tele-actor.net/introduction.html; and http://ford.ieor.berkeley.edu/projects/tele-actor-project.html)