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Fifty years ago, Doug Engelbart created a conceptual framework for augmenting human intellect in the context of problem-solving. We expand upon Engelbart's framework and use his concepts of process hierarchies and artifact augmentation for the design of personal *intelligence augmentation* (IA) systems within the domains of memory, motivation, decision making, and mood. This paper proposes a systematic design methodology for personal IA devices, organizes existing IA research within a logical framework, and uncovers underexplored areas of IA that could benefit from the invention of new artifacts.

H.1.2 [ ]

Design; Human Factors

Intelligence augmentation; intelligence amplification; intellect augmentation; man-computer symbiosis; co-evolution; memory; decision making; motivation; mood regulation

Futurists and science fiction writers have long envisioned a bionic, hardware-augmented future in which humans and machines merge to form powerful new entities [Halacy, 1965]. Humans would build hardware appendages to correct physical shortcomings, better perceive their surroundings, and perform superhuman tasks. Most of the research presented at previous Augmented Human conferences focuses on this physical style of human augmentation.

However, it is also interesting to look at software-based augmentation of humans. For many of us, days are spent in front of screens or smartphones, immersed in the use of software. Software enjoys some advantages over hardware such as a faster rate of evolution [Bennett, 2001], easy modifiability by a larger proportion of the population [Resnick, 2009], and modifiability without tools and parts. While hardware is well-suited for overcoming physical limitations such as strength and endurance, it may be possible to use software to address mental limitations, which is the idea we focus on in this paper.

The idea of software-based augmentation grows stronger with the advent of socially acceptable, commercial wearable computers [Google Glass Project, 2012] that contribute a natural platform for software-based intelligence prosthetics. These permanent, always-available prosthetics may have a natural ability to merge with us and make us true man-machine hybrids [Clark, 2004]. In order to build these wearable intelligence prosthetics, we seek guidance from the pioneer of technology-based intelligence augmentation, namely Doug Engelbart, who proposed the most unifying and rigorous thought framework for the field. While other theories contributed individual ideas, we found the structure of Engelbart's framework to be the most effective for spawning new patterns of thought.

We start by revisiting the intellect augmentation framework proposed by Doug Engelbart over five decades ago [Engelbart, 1962] in order to (1) update Engelbart's IA framework for personal wearable devices of the 21st century, (2) propose a logical design pattern for new IA devices (3) place existing IA artifacts within context, and in such a way to (4) identify IA areas that may benefit from additional research activity and conceptualize new devices.

Engelbart studied how augmentation could make humans better problem solvers. He chose to think about intellect augmentation as a systems engineering problem in which humans do not exist singularly but rather as part of a larger system consisting of a Human using Language, Artifacts, and Methodology in which he is Trained--which he calls the *H-LAM/T system*. Engelbart noted that when humans approach a problem solving task, we have *processes* or "little steps or actions" to call upon as we tackle various parts of the problem. The entire problem-solving task is composed of numerous processes in the form of a *process hierarchy*. When augmentation occurs, it is not of the human itself, but rather of the system as a whole and how the system interfaces with its process hierarchy. Therefore, augmentation can be accomplished by making improvements to any part of the system (artifacts, language, methodology, and training) in a way that changes the process hierarchy for a task.

In this paper, we choose to address how human intelligence can be augmented through physical items, which Engelbart calls "artifacts". Physical items are considered augmentation artifacts if they facilitate or simplify a process hierarchy in a way that enhances our behavior. Although our focus is on IA through the introduction of artifacts, it is informative to spend at least the rest of this paragraph considering Engelbart's alternative forms of augmentation. Augmentation through language warrants a special mention, as it duly notes how naming useful concepts and ideas in order to make them more easily referenced and accessed in the future, is a form of intelligence augmentation in itself. Augmentation through language is frequently used in academia; by coining a useful term, we give others an easy handle to pull up the same idea in the future, allowing them the ability to build new complex ideas out of previously named ideas. Engelbart also

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mentions augmentation through training (improving the training techniques available for learning new abilities) and augmentation through methodology (developing more effective procedures for completing a particular task). Interestingly, artifacts may be able to address these two forms of augmentation as well, if the artifact can change our learning processes in such a way to affect training or our process hierarchies in such a way to change methodology.

In this section, we propose two new interpretations to Engelbart's original framework: a more personal angle for augmentation and the logical extension to new cognitive domains. Although the concepts behind human-artifact interaction remain the same, computing has undergone significant developments since Engelbart's 1962 paper. Computers have evolved from mainframes shared between many users for the processing of batched computational tasks towards personal computers that dictate a direct and responsive style of use. Nowadays, we are surrounded by increasingly inexpensive personal computers of all varieties: smartphones, tablets, and laptops. They are quickly becoming extensions of ourselves by subsuming aspects of our daily responsibilities, such as remembrance of contacts, notes, and our calendar [Sparrow, 2011].

Computers are becoming wearable devices perceptive of an individual user's environment and actions [Schilit, 1994] [Starner, 1997]. Always-on input/output channels may offer even greater levels of integration: affective sensors to probe user state and mood [Picard, 1997], always-on cameras to identify the field of attention [Starner, 1997] [Mann, 1997], cameras to observe the action of hands [Mistry, 2009], tiny accessorizable projectors [Mistry, 2009] and heads-up displays [Google Glass Project, 2012] that offer information even when the user is not deliberately focused on the device. Given the evolution of computers towards highly personal, wearable, always-on devices, we will revisit Engelbart's idea of "co-evolution" from the angle of personal computing, and reconsider what the technology can do for us.

Update #1: A personal view of human-machine "co-evolution"

In his paper, Engelbart used the evocative and biologically-inspired term "co-evolution" to describe the relationship between humans and technology. Engelbart observed that technology influences human evolution because our journey through time passes through one of many possible future *states* and tends to probabilistically follow the path of least resistance. When a technology enables us to perform a certain task more easily, we are more likely to perform that task than we were before. Because the development of technology is the summation of many individual tasks, each new technology influences which future technologies are more likely to be developed, creating an intertwined feedback loop between human actions and technology development.

We believe that Engelbart's view of co-evolution has a powerful corollary. He showed that our creations change human behavior and the evolutionary path of mankind. As designers and engineers, we should ask "how would we like to change mankind?" and design technologies that make it easier to achieve that desired state, causing the state to become more probable.

While Engelbart discussed co-evolution for mankind and technology, we believe it is useful to think about the co-evolution of an individual and *his own* technology. Imagine a future in which we intentionally "co-evolve" with the software running on our personal devices. As individuals, we may be able to program or instruct our devices to induce changes in ourselves, thereby endowing us with the ability to sway the course of our individual evolution.

This leads us to a different philosophical corollary. While Engelbart's view of co-evolution causes us to think about how to design technologies in order to change mankind, this alternative view of co-evolution lends the questions "how would I like to change myself?" and "what programs can I employ to change myself"? We believe that this personal enhancement perspective lends itself to interesting possibilities for a self-directed, personal, and customizable augmentation of intellect that may even be used to revisit the problem solving domain.

In addition, this powerful idea of having a system that learns about one particular user while the user learns about the system, creates for an exciting co-evolution loop [Clark, 2004] that harkens back to Licklider's original vision for man-computer symbiosis [Licklider, 1960].

Update #2: New cognitive domains

The second way in which Engelbart's framework may be updated is a simple domain shift. Intellect is more than just problem solving ability, which was Engelbart's main focus. While people can obviously benefit from help with problem solving activities, they may benefit as much or more from augmentation of non-problem solving aspects of human intellect. The remainder of this paper applies Engelbart's framework to the augmentation of other areas of interest such as memory, motivation, decision making, and mood. The list of cognitive domains that we chose to address is very much a partial list and lacks important aspects of intellect such as emotional intelligence [Goleman, 2006] and sensory intelligences [Gardner, 1985]. We selected our short list by personal interest and the amount of pre-existing work in each of the domains.

As summarized and liberally extrapolated by the authors, the following steps describe how it is possible to use Engelbart's framework for the design of IA artifacts. Our apologies if this extrapolation ventures beyond Engelbart's original intent.

Step 1: Consider the desired state after augmentation

Engelbart considered his *desired state* after problem solving augmentation. He decided that problem solving augmentation could be considered a success if humans were able to achieve "more-rapid comprehension, better comprehension, the possibility of gaining a useful degree of comprehension in a situation that previously was too complex, speedier solutions, better solutions, and the possibility of finding solutions to problems that before seemed insoluble."

Step 2: Identify the processes for the task

Engelbart studied the memo-writing process to illustrate some of the processes involved in problem solving. He noted that the memo-writing process consisted of sub-processes such as "planning, developing subject matter, composing text, producing hard copy, and distributing."

Step 3: Identify how artifacts can change a process or the process hierarchy

Engelbart proposed the introduction of a typewriter artifact allowing for the copy-paste of text. He remarked that "this writing machine would permit you to use a new process of composing text... you can integrate your new ideas more easily, and thus harness your creativity more continuously, if you can quickly and flexibly change your working record... which in turn enables you to devise and use even-more complex procedures to better harness your talents in your particular working situation."

In summary, to design new augmentation artifacts, we will first consider our *desired state* for each domain of human intellect that we plan to augment. We then consider the *processes* in use for that particular domain. Lastly, we examine which *artifacts* we can introduce in order to alter some of the processes so as to make our desired state more probable. The contribution of this paper lies in the expansion of Engelbart's framework to other domains of intellect in order to provide a more systematic classification of research projects and to uncover underexplored areas of intellect augmentation that could benefit from the invention of new artifacts.

In this section, we hope to demonstrate the usefulness of applying Engelbart's framework to think about the augmentation of new cognitive domains. By organizing existing research into Engelbart's structure, we are able to systematically find processes that could benefit from augmentation and propose novel artifacts.

For each of the subsections, we will follow the same structure. We first present background literature that may provide relevant information for the domain of augmentation. We subsequently try to discern a desired state of augmentation as well as candidate processes to attack. We associate existing research artifacts with our list of processes in order to find underserved processes that can be addressed by the design of new processes. Although space constraints force us to be brief, we believe that even shallowly exploring each domains in this manner demonstrates the appropriate thought process of how the framework can be used to organize and design personal IA systems.

We begin with a domain that has received much attention in prior work, augmentation of long-term memory. Any discussion of memory necessitates clarification as to the type of memory in question. To ground the discussion, we choose to concern ourselves with declarative memory, the memory for conscious recollection of facts and events [Squire, 1992]. The end-goal for declarative memory augmentation may be differ from person to person. Students may desire the ability to store and access large tomes of information that they have only read once. Elderly people may wish to address memory loss or archive their memories for posterity. Others may desire the ability to forget bad memories.

Memory researchers say we use two types of declarative memory in our daily lives: *semantic memory* for encoding abstract information about the world and *episodic memory* for encoding an individual's personal experiences [Squire, 1998]. According to at least one memory model, these two types of memory may be interconnected in the sense that encoding of information for the episodic system depends critically on the semantic system [Tulving, 1998]. In Tulving's view, "the two systems share many features, but episodic memory has additional capabilities that semantic memory does not."

It is interesting to note that the artifacts we have in our possession today, such as the web and digital storage devices, are helpful for supporting the simpler semantic memory, and we may have already adapted to having such tools readily available for memory augmentation. Research has shown that we have lower rates of recall when we believe that information can be found easily on a search engine [Sparrow, 2011]. We seem to lack popular artifacts for the encoding and recall of (1) purely episodic information and (2) information that exists as closely related content in both episodic and semantic memory. Memory augmentation artifacts may want to expand functionality to these two areas.

Table 1 presents an analysis of the processes involved in everyday memory is written from a simplistic computational perspective and does not do justice to all processes involved, but nevertheless provides a useful basis for discussing existing memory augmentation artifacts in Table 2 and postulating about viable memory artifacts of the future. In fact, it would serve the reader well to propose an alternative list of processes involved in memory, as that would allow the reader to conceptualize a drastically different set of viable artifacts.

Event recording	Write the experience to the brain in terms of both factual detail and emotional state.	Write errors may occur so that stored information is lost or distorted.
Handle attachment	Attach relevant "hash tags" or "handles" to the experience in order to retrieve the memory in the future.	Relevant handles may fail to be attached, causing a future failure to retrieve a relevant memory.
Handle usage	Convert the situation to a set of handles and use these handles to search within our brain for potentially relevant memories.	A failure may occur during the conversion of the real-time experience to the entire space of relevant handles, causing a failure to retrieve a relevant memory even though the memory has been stored in the brain.
Event playback	Read the memory associated with that handle.	Our stored memory may have holes. Worse, we may not realize that our memory has become distorted, colored, or incomplete and believe that our version of the experience is correct [Winograd, 2006].

Forget-me-not [Lamming, 1994]	Device that logs and timestamps all digital interactions a user makes with devices and other users. Offers the user access to events based on tags.	Episodic	Event recording; Handle attachment
Remembrance Agent [Rhodes, 1997]	Device that senses the current environmental context in order to suggest previously accessed material that may be relevant.	Semantic and episodic	Handle usage
Memory Glasses [DeVaul, 2003]	Glasses for enhancing face-name recognition. Users are given time to learn names and faces. Users while wearing the glasses are subsequently quizzed on the name associated with a particular face. A subliminal message containing the name is flashed quickly within the glasses in attempt to unobtrusively assist in name recall.	Semantic	Handle usage
Iremember [Vemuri, 2006]	Device that records audio heard in daily life. The audio clips are stored and automatically organized by time and contextual events such as weather, calendar events, and email.	Episodic	Event recording; Handle attachment; Event playback
SenseCam [Hodges, 2006]	Camera that takes automatic and sensor triggered pictures of the user's daily life. Software allows for playback and bookmarks of still shots. Sensecam was a purchasable product [Vicon Revue].	Episodic	Event recording; Event playback

Observe that all identified memory processes without an associated artifact have potential for artifact augmentation. Since the majority of the experimental memory artifacts (Table 2) has attempted to address the capture and recall of pure episodic memory, additional research may want to focus on the creation of artifacts that assists in the encoding and recall of closely related episodic and semantic memory. For example, a potentially useful innovation may be an artifact that automatically associates newly acquired semantic information with hash tags and visually presents these hash tags to the user. This artifact would serve to augment the *handle attachment* process and allow for additional semantic information to be easily pulled from the web. Another artifact operating dually between episodic and semantic memory might overlay one user's personal reaction when exposed to some stimulus to the reaction of users who experienced the same stimulus. This artifact augments the *event recording* process and allows for the creation of richer, social experiences (in a similar fashion to [Liu, 2004] but with different intent.)

The field of technology-based augmentation of motivation has been given attention in the context of diet and exercise. Yet, we may still desire more universal motivation for sticking to general long-term goals. Perhaps it is difficult to remain motivated to new goals because a large proportion of human behavior is composed of unconscious, fully-automated habit loops [Wood, 2007]. If this is the case, and technology can assist in the creation of new habits [Oulasvirta, 2012], artifact introduction may be an exceptionally potent way for technology to support us in desired changes of behavior.

To be slightly more systematic in our analysis, we may look towards what management science has identified to be the processes behind motivation. In particular, VIE motivation theory [Vroom, 1964] claims that the decision to complete a task is dependent upon the valuations of the three discrete components: valence (perception of reward), instrumentality (perceived correlation between effort and task performance), and expectation (perceived correlation between task performance and reward).

Although important, the task evaluation processes described in management science literature does not comprise all of a motivation framework. We may also want to incorporate higher-order goal formation and execution methodologies such as those described by Allen in his popular book on motivation [Allen, 2001]. As described in the previous section, our list of processes by no means needs to be complete or "correct", but rather offer sufficient enough structural backbone for the conceptualization of new artifacts and the organization of existing artifacts.

Self-evaluation of performance	Evaluate personal performance and distance to goal (i.e. through logging, incorporation of external feedback, or relative comparison to others).	Evaluation may be distorted; Evaluation may not occur
Reminder of goal	Remind self of goal and reaffirm commitment.	Goal may be forgotten; Goal may be forsaken
Task identification	Identify a set of tasks that would aid in advancement of the goal.	Subject may be unable to convert long-term goals into discrete actionable tasks
Task evaluation	Evaluate if performing the task is worthwhile which according to VIE motivation theory [Vroom, 1964] consists of valence perception, instrumentality evaluation, and expectation evaluation.	Evaluation may be distorted; Evaluation may not occur

Study Buddy [Fogg, 2005]	Hypothetical concept artifact which socially motivates students to study by displaying other students who are studying at the same time as well as the study patterns of "mentors".	Self-evaluation of performance; Reminder of goal
Weight Loss Robot [Kidd, 2007]	Robot helps a user track information related to his or her weight loss regimen and reacts with the user in a socially appropriate manner as the robot-user pair being to develop a relationship.	Self-evaluation of performance; Reminder of goal
UbiFit Garden [Consolvo, 2008]	Background of the cell phone screen grows flowers when a user exercises. Flower species represent different exercise types.	Self-evaluation of performance; Reminder of goal

After consideration of the processes involved in motivation (Table 3) and existing artifacts (Table 4), we suggest that additional work in augmenting motivation may want to explore how artifacts can aid in *task evaluation* processes. For instance, it may be possible to augment the *valence perception* process with an artifact that allows users to psychologically experience the valence of a particular reward and how good it feels to succeed. It may be possible to augment the process of *expectation evaluation* through an artifact that helps us better visualize the correlation between performance and reward, by showing how our individual performance on a task stacks up against other users performing the task.

Decision making augmentation tries to address the problem that humans are noticeably inconsistent. We set long term goals for ourselves, but have difficulty syncing our short term actions with our long term intent. We have ethical frameworks and belief systems that we value when we consciously stop to think, but our default behavior may remain unfounded due to irrationality and cognitive dissonance [Ariely, 2009]. Context-aware software may be able to assist in some of our short-term decisions, and make us more aware of the long-term consequences of our daily behavior.

We want the decisions we make to be correct with respect to our value systems, quick when considering the mental processing time required to reach the decision, and confident in that we know that we made the correct choice. Artificial intelligence researchers have long experimented with the design of computerized expert systems that can aid [Barnett, 1987] [Sharda, 1988] or replace [Buchanan, 1984] [Duda, 1982] human experts in making professional decisions. Little work seems to been done in terms of a general device to aid real-time decision making in daily life, although one recent doctoral thesis did explore the design of a large array of specialized, just-in-time devices to aid daily decisions [Sadi, 2012].

Since artifact-based, real-time decision making is so underexplored, most processes in Table 5 are without associated artifacts. It may be of interest to build an artifact that assists users with framing decisions in the context of available options. To continue the Reflectons example described in Table 6, an interface may inform a user at dinnertime that he has the choice between taking five, fifteen, or thirty minutes out of his schedule to eat dinner. By framing the decision explicitly and asking the user to commit to a choice, the artifact has augmented the processes of *decision recognition* and *decision framing*, and probably aided the user in the goal of not eating too quickly. Another artifact might be a wearable that asks users to pre-program a set of adjectives they strive to be, such as "generous", "kind", and "inquisitive." The wearable would alert the user when he has the opportunity to make a decision that fits one of his pre-programmed attributes. For instance, the artifact may make the suggestion to be generous when the user encounters someone asking for change, to be kind when encountering a cashier having a rough day, or to be inquisitive when passing a stack of books in the library. This artifact would aid the user in the processes of *value system formation* and *value system reconciliation*. The same artifact could also gently provide us with information on how we are faring with respect to other people who have chosen the same attributes as we do, so as to augment the process of *knowledge acquisition* and facilitate improvements via social comparison.

Knowledge acquisition	Acquire learned knowledge relevant to the decision either passively or actively and potentially over extended time periods.
Value system formation	Define or choose not to define an internal value system.
Decision recognition	Recognize that it is the appropriate context, or situation for making a decision.
Decision framing	Frame the decision in terms of time and choices available.
Value system reconciliation	Reconcile the choices with internal value system and learned knowledge and select a decision.

Reflectons [Sadi, 2012]	Mental prostheses for delivering just-in-time information as users make daily life choices. For instance, a spoon lights up to indicate when its holder might be eating too quickly, an indicator of unhealthy eating practices that may lead to weight gain.	Framing the decision; Value system reconciliation

Decision making has incredible potential for artifact augmentation and co-evolution between people and their artifacts. Our actions shape who we are. Our future decisions are based on making relative comparisons with past decisions. By aligning our decisions with our internal beliefs and equipping our decisions with relevant information, we decrease error rates and become closer to who we truly want to be.

Mood is defined as an affective phenomenon that differs from emotion by its nonspecificity and pervasiveness [Morris, 1987]. In other words, emotion is targeted toward a particular object whereas for mood the causal origin is unknown [Isen, 1984]. The nonspecific and pervasive nature of mood further incentivizes us to build artifacts to manage it since by definition it is enigmatic and omnipresent. Humans self-report internal psychological methods that we use for regulation [Josephson, 1996], but these systems often fail as even highly performing individuals can be inefficient and plagued with low morale or other mood problems. Rather than define an ideal desired state of mood and design artifacts for perpetually remaining in this ideal state, it may be easier to create artifacts for correcting negative mood states. It is of particular interest to consider a computational approach to mood-regulation as it would allow for fine-grained control and "self-medication."

The processes involved in mood seem to be ambiguous so we have no table to present. However, behavioral biologists have postulated that mood correction consists of a two-part self-regulatory system of recognizing a bad mood and subsequently taking corrective action such as self-reward, modification of problem significance, problem-directed action, or social affiliation [Morris, 1987]. Therefore, both the design of artifacts that help actively recognize a bad mood as well as those that facilitate active, corrective behaviors may help people manage mood issues.

In terms of existing artifacts, medicine has explored chemical-based ways of mood enhancement [Knutson, 1998] [Chatterjee, 2004]. There have also been advancements in computer-aided cognitive-behavioral therapy (CCBT), in which a computer uses patient input to make computations and treatment decisions [Marks, 2007]. CCBT may involve a computer program teaching a patient methods that can be used to manage mood. However, CCBT typically involves a highly specific program targeted towards one particular ailment, rather than a general mood management approach.

It may be of particular interest to consider mood improvement for healthy or even happy people. The field of positive psychology addresses the benefits of making normal people happier, in what they call the broaden-and-build theory [Fredrickson, 2001]. This theory argues that when people experience positive emotion, they broaden their thought and action repertoires in such a way to build enduring long-term resources, whereas negative emotion triggers preservation instincts that do not allow these long-term resources to be developed. Additionally, positive emotions were found to build resiliency that can counter subsequent negative emotions and engender "upward spirals" toward emotional well-being [Fredrickson, 2002].

A positive psychology mood alteration artifact may be able to incorporate other behavioral biology research such as literature on primes. For instance, a passive mood management approach may take advantage of how affect-inducing events can prime similarly toned thoughts and memory [Isen, 1978]. An artifact may display primes to influence our objective perception of neutral stimuli [Murphy, 1993] or to facilitate creative thought [Isen, 1987]. Devices of this type would deliver stimuli designed to induce changes in mood without conscious thought on the part of the user, in contrast to the active mood management techniques described in the previous paragraph.

Although the study of mood may be quirky, mood alteration artifacts make a first attempt at interfacing with an opaque area of our minds, offering an exciting avenue for software units to dispatch triggers that can produce desired changes in behavior.

Measurement

It is interesting to note that in the augmentation domains that we consider, contain an iterative process or cycle in which what we are trying to augment implicitly gets (or should get) measured. Therefore, any artifact that measures the domain aids in the augmentation process, and the very act of measuring the domain might cause it to improve. These measurement idea easily lends itself to artifact-based augmentation and resonates with the quantified self movement in which users self-track in order to improve performance [Wolf, 2010].

Imagine that you are endowed with an artifact that makes it easy to measure and record the number of new people you have met during the day. If yesterday you met three new people, and you were made aware of the fact today, you might feel pressured to meet or exceed yesterday's number. If you were not keeping track of the daily number, yesterday's achievement would have no positive bearing on your actions today. Effectively this means that even if the artifacts we design for augmenting aspects of cognition do not function perfectly, we may get at least an initial improvement in functionality purely based on this measurement and increased awareness phenomenon.

Populations

Useful parallels with the biological sciences need not end with co-evolution. In his 1962 paper, Engelbart lamented how "each individual tends to evolve his own variations, but there is not enough mutation and selection activity, nor enough selection feedback, to permit very significant changes." Fifty years later, if we can significantly extend humans via software, we will create a new population of "superorganisms" capable of sharing effective self-augmentation ideas in the form of software code. Successful members of the population may easily swap these ideas or "variations" with others, fostering an environment for rapid evolution. It has not escaped our notice that the specific evolutionary scenario we have postulated regarding software code has a biological equivalent in genetic code.

Additionally, the idea of defaulting to a population's expertise is not new and has been well-explored by use of the term "collective intelligence" [Levy, 1999]. The idea has been heavily and successfully tested in the Internet Era through the use of music [Shardanand, 1995], product [Linden, 2003], and news [Das, 2007] recommender systems. It may now be time to retry the population's wisdom in the era of personal wearable computing.

As we embark on the design of artifacts for cognitive augmentation, we should carry with us Engelbart's co-evolution corollary, remembering that the technologies we create end up changing the course of human evolution.

We must be aware of the potential of adversarial interference by parties who attempt to tamper with our augmentation processes and employ robust technological security measures. As suggested by [Sparrow, 2011], we must be aware that users may become dependent upon their software and ensure that users still function at a pre-augmentation level when not using a particular artifact. We need to design artifacts while respecting that augmentation is a highly personal and sensitive activity. It is especially important that users experience interfaces that are profoundly configurable, unobtrusive, and consensual.

Design considerations aside, numerous ethical questions surrounding enhancement versus treatment remain, and have been considered by medical doctors [Chatterjee, 2004]. Their concerns include the questions: does augmentation detract from our personhood? Will this encourage further resource disparity? Will people be pressured to use IA technology?

Given the recent evolution of human-computer interfaces, there is enormous potential for creating technologies that augment domains of human cognition such as decision making, mood and motivation. Engelbart's original paper is useful in analyzing these opportunities and offers many unexplored ideas for personal IA readily implementable in the age of wearable computing. Augmenting human intelligence creates the powerful feedback loop that Engelbart described as increased intelligence leading to new technological developments in the intelligence augmentation arena, leading to further increased intelligence.

Using Engelbart's framework of processes and artifacts, we can identify underexplored domains for intelligence augmentation and begin on this odyssey. The framework presented in this paper offers a strong structural foundation for exploring the fresh, untrodden terrain of personal, mental augmentation. We hope you have been inspired to design.

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